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NATIONAL GEOGRAPHIC

The cells of a patient's heart, lungs, liver, kidney, brain—you name it—can be replicated on this chip to help researchers develop individualized treatments.

THE FUTURE OF MEDICINE

HOW NEW TECHNOLOGIES AND ANCIENT REMEDIES ARE TRANSFORMING HEALTH CARE

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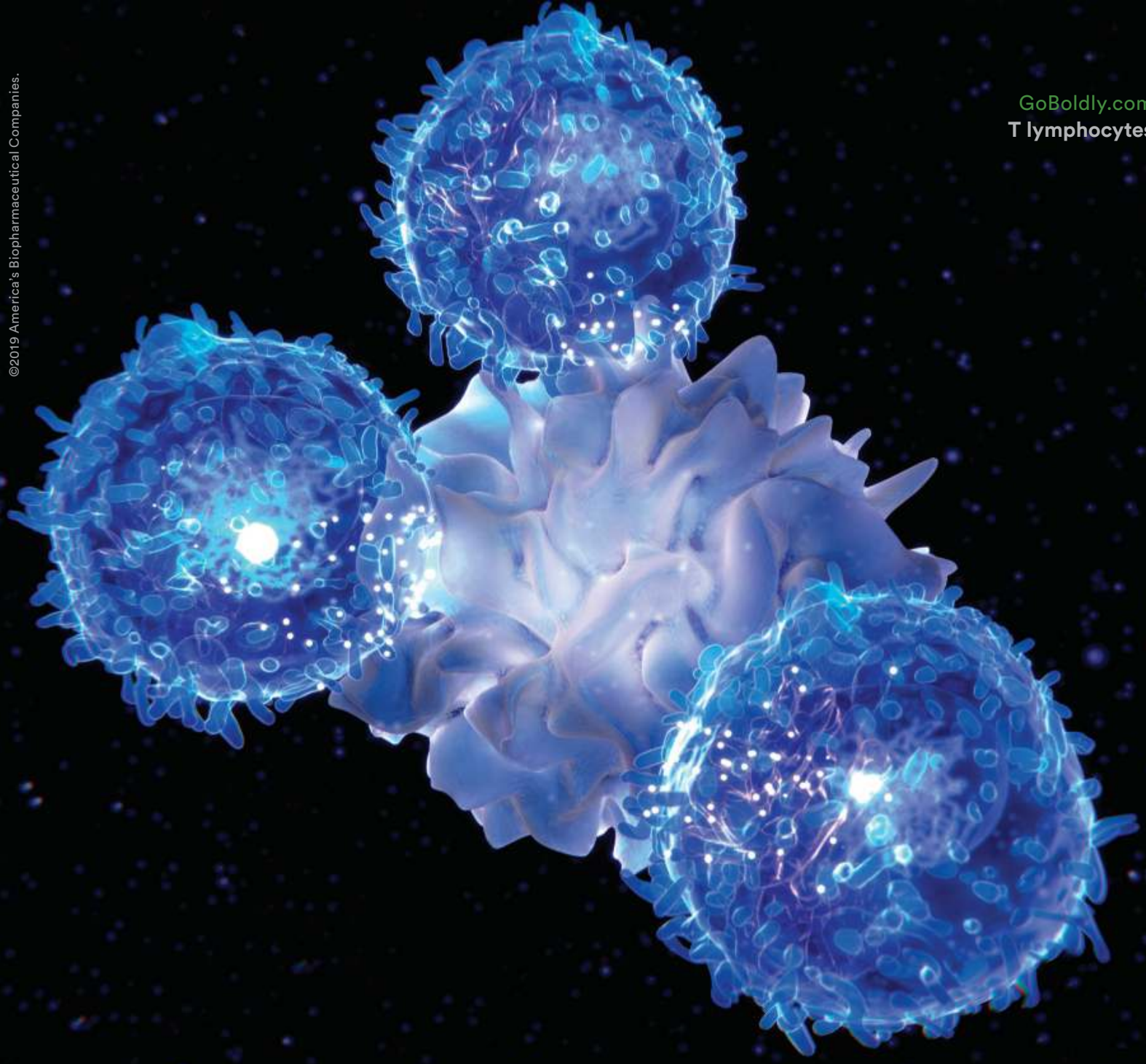

T lymphocytes

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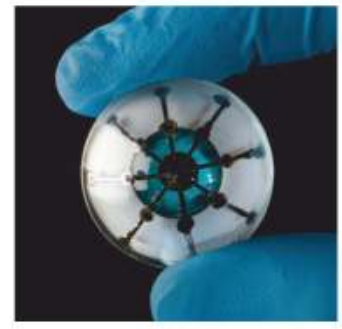
CONTENTS

On the Cover
This composite photo shows highly magnified, functioning spinal cord tissue (background) that's micro-engineered onto a chip, which researchers can use to study disease.

CRAIG CUTLER (HAND WITH CHIP); SAMUEL SANCES, CEDARS-SINAI (BACKGROUND)

SPECIAL ISSUE: MEDICINE



FEATURES

Andean Flamingo *(Phoenicoparrus andinus)*

Size: Height, 100 - 140 cm (39.4 - 55.1 inches); wingspan, 160 - 180 cm (63 - 70.9 inches) **Weight:** 2 - 2.4 kg (4.4 - 5.3 lbs) **Habitat:** Found primarily on high Andean plateaus **Surviving number:** Estimated at approx. 38,000

Photographed by Chris Stenger

WILDLIFE AS CANON SEES IT

Micro eater. The Andean flamingo's bill features a sieve that filters particles approximately the width of a human hair from the shallow water of salt lakes. During breeding season, this striking bird devotes more than 80% of its time to feeding; during the winter, it spares more time for social interactions and displays. But over time its breeding sites have been compromised due to activities including mining and large-scale water usage. With this habitat degradation, the challenges ahead are anything but small.

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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This 1984 photo shows Bill Gates, left, and the late Paul Allen. The two founded Microsoft, one of the companies featured in *Valley of the Boom*.

NAT GEO TV

Witness the Birth of Tech in *Valley of the Boom*

In the 1990s Silicon Valley attracted hordes of inventors, investors, and con artists eager to join the technological revolution. The six-part series *Valley of the Boom* combines scripted storytelling with documentary interviews to chart the meteoric rise and cataclysmic burst of the dot-com bubble, through the lens of three companies that were trying to change the world with technology. The series premieres on January 13 at 9/8c, on National Geographic.

TELEVISION

Climate Change from *Paris to Pittsburgh*

Set against debates about the United States' exit from the Paris climate accords, the film *Paris to Pittsburgh* captures the impassioned efforts of people battling the severe threats of climate change in their own backyards. Produced by Bloomberg Philanthropies, the film is available now on the Nat Geo TV app.

BOOKS

Give the Gift of Knowledge: Our 2019 Almanac

From ancient sites hailed as wonders of the world to scenes of deep space, the 2019 *National Geographic Almanac* takes readers on a 400-page voyage of discovery. Packed with trivia quizzes, infographics, maps, time lines, and images, it's available where books are sold and at *shopng.com/books*.

CHICHÉN ITZÁ, an ancient Maya city in Mexico's Yucatán state, was named one of the New 7 Wonders of the World in an international poll published in 2007.

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PHOTOS, FROM TOP: DOUG WILSON; JOSE IGNACIO SOTO

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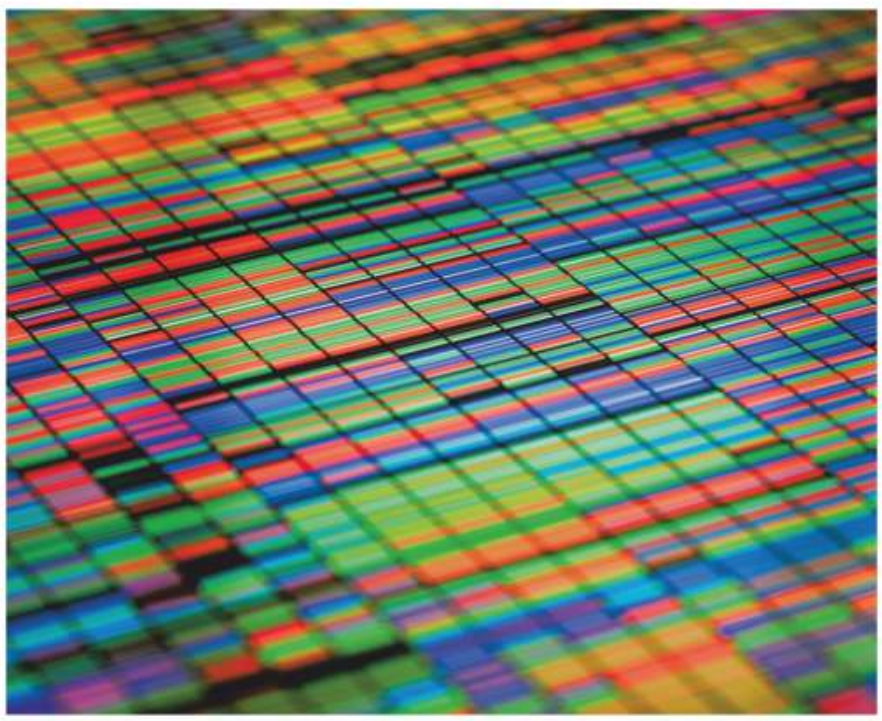
EVERY BIT EARNED

SPECIAL ISSUE

Into Medicine's Future

BY **SUSAN GOLDBERG**



To sequence a genome, long strands of DNA are cut into small pieces. Then each is analyzed to determine the arrangement of DNA's four base chemicals—adenine, cytosine, guanine, and thymine—seen in this illustration as different colors.

WHEN WE ASKED veteran journalist Fran Smith to write about new frontiers in medicine for this month's issue, the first thing she did was volunteer to be, in her words, "a research guinea pig." She got her genome sequenced.

Smith didn't hesitate. After all, she told me, she's never understood some people's skittishness about medical testing and learning what may—or may not—loom in their health future.

"You're not safer if you don't know," she says, sensibly enough. "And you can find out things that are very useful and that you can do something about."

Smith wanted her own experience of what's come to be known as "precision medicine." Unlike older medical models that tend to lump patients together and treat them for a category of illness, this approach uses gene research and data analytics "to tailor prevention, diagnosis, and treatment to a person's unique biochemical makeup," Smith writes. And in decades to come, its advances will "upend the way medicine traditionally has been practiced."

At Stanford University, where she enrolled in a detailed biochemical profiling study for this assignment, Smith's experience began not with needles or swabs but questions from a genetic counselor.

"Did I understand that DNA sequencing might produce 'actionable' results, such as *BRCA* mutations for breast and ovarian cancer, the problem that had famously spurred Angelina Jolie to undergo a preventive double mastectomy?" Smith writes. "Did I understand the test also might reveal problems I can't do anything about, such as the *APOE4* gene, which elevates the risk of Alzheimer's? Did I want to learn all findings?"

I won't spoil the story, but as Smith notes, while she awaited the test results, "my stomach surprised me by knotting in protest." Would she find out that she might follow her father's fate—a slow decline into dementia? Or might she more resemble her mother, still living on her own at age 94, playing mahjongg and dancing at the senior center?

Another surprise: Smith told me later that she was fascinated to learn that the same genetic counselor who asked her all those questions has not had her own genome sequenced. She hasn't decided if she wants to know.

As researchers develop tools not imagined even a decade ago—to edit our genes, predict our risk of disease, even shape the biomedical future of our children—individuals and societies must think critically about the implications. We believe that's best done on the basis of sound facts and science, the foundation for the coverage you'll find in this special issue.

Thank you for reading *National Geographic*.

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PROOF

NATIONAL GEOGRAPHIC

PHOTOGRAPHS BY **GABRIELE GALIMBERTI**

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

HOME PHARMA

People from around the world empty their medicine cabinets to reveal the cures they keep.

VOL. 235 NO. 1

ITALY Remo Ballardini, a librarian in Riva del Garda, shows his home pharmacy's contents: items for both treatment and prevention, including a topical antiseptic.

SWITZERLAND Art collectors Candelita and Arnaud Brunel have a voluminous trove of medicine.

ITALY Andrea Buccolini keeps salve handy for bruises earned as a reenactor of ancient Roman battles.

BOTTOM PHOTO: EDOARDO DELILLE

INDIA Most of this Mumbai family's medicines are for Abbas Ali Sagri (seated at right), who had a stroke.

LATVIA Ingrīda Pulekse, a retired schoolteacher, takes few pills now but saves those from past illnesses.

HAITI Wholl-Lins Balthazar (left), pictured with her mother-in-law and cousin, relies on traditional

Haitian medicine, mainly plants from local markets or from a leaf doctor, known as a *medsen fey*.

COSTA RICA His parents bought but haven't yet given medicine to Johan, seven (third from left), for ADHD.

JAPAN Yasumasa and Nobuko Kawai use drugs to treat his heart condition and her osteoporosis.

FRANCE Alexis and Aurélie Chauffert-Yvart use many medicines, from antianxiety drugs to antibiotics.

COLOMBIA Hilda Tarazona (right), her daughter, and her granddaughter share a home and medicine cabinet.

THE BACKSTORY

HIDDEN AWAY IN THE WORLD'S BATHROOMS AND CABINETS, PILLS, SYRUPS, AND OINTMENTS PILE UP.

WHENEVER PHOTOGRAPHER Gabriele Galimberti meets people on his travels, he asks the same question: Can I see what's in your medicine cabinet? Some are shy; others proud to do so. "The medicines reveal who the people are," says Galimberti. "Their desires, their wants, their diseases. It's very intimate."

What can our medicines say about us? For one, how affluent we are. Cabinets in developed countries tend to overflow with pharmaceuticals. People in less developed countries collect medications more slowly or not at all. A Haitian woman had not a single pill in the house: "If I get sick, I'll buy a pill from the street vendor," she said.

The medicine cabinet series, "Home Pharma," is part of a larger ongoing project, called "Happy Pills," in which Galimberti and three colleagues document humans' never-ending pursuit of happiness through chemistry. People take pills to be stronger, to sleep more (or sometimes less), to age more slowly, to be more virile, to promote pregnancy, or to prevent it. The reasons people buy medicines—and hoard them—are just as plentiful: because they're cheap or because more advanced medical care *isn't* cheap, because we're anxious about being unprepared, or because we were once prescribed them and don't know how to dispose of the rest.

View the different cabinets' contents, and cultures start to take shape. In Paris and New York, Galimberti saw large numbers of antidepressants and antianxiety pills. Indian people tended to choose medicines with Indian labels, independent of quality or potency. African cabinets had drugs from China, often unlabeled. Yet all the people photographed had something in common: None of them were sick. **—DANIEL STONE**

SWITZERLAND Susan Fischer, a yoga teacher, uses only homeopathic remedies, including plant extracts.

"HOME PHARMA" IS A SPIN-OFF OF A LARGER PROJECT, CALLED "HAPPY PILLS," BY PAOLO WOODS, GABRIELE GALIMBERTI, ARNAUD ROBERT, AND EDOARDO DELILLE.

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Doctor Photographer

STORY AND PHOTOGRAPH BY **MAX AGUILERA-HELLWEG**

HE MADE A CHOICE TO SAVE LIVES RATHER THAN WITNESS THEM THROUGH THE LENS OF A CAMERA. BUT THEN A SURPRISE PHONE CALL MADE HIM CHOOSE AGAIN.

I STOPPED RECEIVING CALLS on my cell phone while I was training to be a doctor. My friends knew better. My life was not my own. As a resident I sometimes worked nearly a hundred hours a week, overseeing as many as 18 patients at once. Even my mom stopped calling me. I used my phone instead for medical apps—the one that could tell me which antibiotic to prescribe for which bug, the calculator that helped me determine treatments, the app that stored lab values I couldn't remember.

Then one day my cell phone rang. I was on rounds seeing patients and stepped out to the hall. I didn't recognize the number, but the area code was Washington, D.C. This call, I thought, must be important. "Yes?" I whispered in the hallway.

"Hey, Max," the voice boomed. "It's Todd." Todd James is a photo editor at *National Geographic*. I hadn't spoken to him in 10 years, certainly not since I'd left photography to become a doctor, but I recognized his Oklahoma twang. "I've got a job for you."

The story was on stem cell research, and he wanted to send me all over the world to shoot it. As Todd talked, my mind reeled—yeah, that was the life, on the road with my camera, with license to explore. Being a photojournalist is like being Zelig, or Forrest Gump, or Walter Mitty: You aren't the important one, but you're right there with whoever or whatever is. I'd been a photographer for 20 years, but I stopped when I realized I didn't want to be the voyeur anymore. I wanted to be having the experience myself.

I'd found a new path when I was assigned to photograph a neurosurgeon performing a spine procedure. The patient was upright, his skull locked in something like a C-clamp, his spinal column stretched out, which allowed the surgeon to operate standing and at eye

level, with clear and clean access. At one point she said, "Here, take a picture of this." There before me was the exposed spinal cord, pristine and white. I realized this thing had never seen light, wasn't meant to see light, and at that moment was bathed in light. I was in awe, as if I'd awoken to find myself in a flight suit on an Apollo spacecraft, heading to the moon. I knew right then that this was where I wanted to spend the rest of my life. I contacted all the magazines I worked for and asked them to give me all their assignments on medicine and doctors. About 10 surgeries later I thought, I could become a doctor myself.

"I don't know," I told Todd. "I've got patients I've got to see right now. I'll call you back." So there I was, finishing rounds, seeing patients, writing notes, being a doctor, totally conflicted. The itch I'd scratched for so many years was still there—that itch of seeing the world; making decisions about color, about light, about what to leave in the frame and what to leave out, about how to tell a story; and the pure joy of looking through a lens. That afternoon I ran into the assistant director of my residency program. He pointed out that I had an elective month coming up. I had the option to spend it doing research. "This story. It's research, right?"

I called Todd right away. He figured I could do the story in 23 days—13 shoots in 13 countries. The first would be in my own hospital, UMass Memorial Medical Center, where there was a clinical trial using stem cells to treat lupus. From there I headed to Europe.

In Berlin I went to the former lab of Rudolf Virchow, the 19th-century doctor who had established that all cells are created by the division of preexisting cells. I wanted to create a picture that illustrated the power of a pluripotent stem cell. By stacking pathological specimens, I made an abstract human: hair from the head of a stillborn infant, a brain, an enlarged heart, a liver, bones, and teeth—all parts of us that could come from a single stem cell.

I'd forgotten how to use a light meter, but the rest came flooding back. Being a photographer is serious business, but I had 20 years of experience doing it. So many things had gone wrong in so many different situations with so many different people that I had figured it out. I was a master. Shortly afterward I began my first rotation in the intensive care unit, aware that it would take 20 more years before I had the mastery I needed—and wanted—to have as a doctor.

A year later, as a resident guiding my own interns, I wondered what to specialize in. Then I knew. I wanted to make photographs again, I wanted to make films, I wanted to tell stories like nothing else mattered. I was leaving medicine—but with hard-won scientific knowledge and experience caring for the ill, a graduate degree in the human condition. I'd received a call I had to answer, the call to create.

As a photographer and filmmaker, **Max Aguilera-Hellweg** specializes in stories about science and medicine. He photographed "The Addicted Brain" for the September 2017 issue.

INTERVIEW

WATCH WHAT

MICHAEL ROIZEN, M.D., is chief wellness officer at the Cleveland Clinic and a *New York Times* best-selling author. **MICHAEL CRUPAIN, M.D.,** is chief medical officer for television's *The Dr. Oz Show.* Both have long linked a better diet with better health. But their new book, *What to Eat When,* says emerging science confirms that "when you eat is as essential as what you eat for maintaining a good weight, preventing and curing some diseases, and living a long, energetic, and happy life."

Ahead of the book's December release, the doctor-authors answered questions for *National Geographic.*

Tell us about the science behind your approach to eating.

We're all familiar with our biological clocks—the circadian rhythm that sends out chemical signals at certain times to help us wake, sleep, and do other activities. Well, we also have a food clock with a similar purpose: to sync our consumption of food with chemical reactions in the body.

According to these clocks, the optimal way to eat is to consume more energy earlier in the day and less energy later in the day. But our bodies crave the opposite—more calories at the end of the day and fewer in the morning. This is a holdover from a time when humans' food supply was unreliable and storing energy was an advantage. Today this schedule of eating has negative effects on our health: Studies in animals and humans have associated it with weight gain, chronic disease, and premature aging.

So we need to override that craving-driven schedule and eat in a way—more early, less later—that aligns food patterns with our internal clocks. We call this chrononutrition.

What are the guiding principles in this system of eating?

A few adjustments to existing eating habits will help sync up our internal systems. Two are especially important:

—AND WHEN—YOU EAT

1) Limit your eating to when the sun shines—a window of about 12 hours or, better yet, fewer. That means cutting out nighttime refrigerator raids.

2) Eat more in the morning and midday and less later on. Your body will work best—and be healthier—if you preload calories rather than save them until later in the day, as many of us do.

We help people learn how to do this day to day. But we also define "when" another way. Our bodies change depending on what's going on in our lives—so we may need to adjust what we eat to be at our best. In the book we list common situations, suggest the best things to eat to prepare for them, and explain the science behind our advice.

What benefits do you tell people they'll derive from eating this way?

The endgame is that this way of eating will extend your own endgame. It will help prevent disease and, in some cases, even curb or reverse disease. Following this plan can result in all kinds of improvements to your quality of life: better sleep, more energy—and just overall better health.

THIS INTERVIEW WAS EDITED FOR LENGTH AND CLARITY.

Eating certain foods helps your body deal with specific life situations, according to *What to Eat When*. Here's what the book suggests you eat:

WHEN YOU'RE HANGRY

Roasted chickpeas. They have healthy protein and fiber plus the crunch and satisfaction that hungry, angry people crave.

WHEN YOU'RE GOING ON A FIRST DATE

Calm nerves with pre-date foods that increase energy levels slowly: avocado, walnuts (good fats), and sliced turkey (healthy protein) on whole-grain toast (complex carbs).

WHEN YOU'RE SICK

Grandma was right: Chicken soup is helpful, for a couple of reasons. It affects the viscosity of mucus, and it contains ingredients that have anti-inflammatory properties.

WHEN YOU HAVE A JOB INTERVIEW

For breakfast, sprinkle oatmeal with ground flax, a source of healthy fat and vitamins that help boost concentration and cerebral cortex function. Coffee helps sharpen attention and problem solving; have one or two cups—not more—45 minutes before the meeting.

WHEN YOU WANT TO PROTECT YOUR BRAIN

Salmon contains the healthy fats that have been shown to protect your brain against memory-related problems. A favorite of Roizen's: salmon burgers for breakfast.

WHEN YOU GET A LOT OF HEADACHES

Spinach. It contains B vitamins and other nutrients that have been shown to help reduce the incidence of migraines.

WHEN YOUR FAMILY IS PRONE TO CANCER

Lots of vegetables, especially cruciferous ones (cauliflower, cabbage). They're loaded with disease-fighting nutrients.

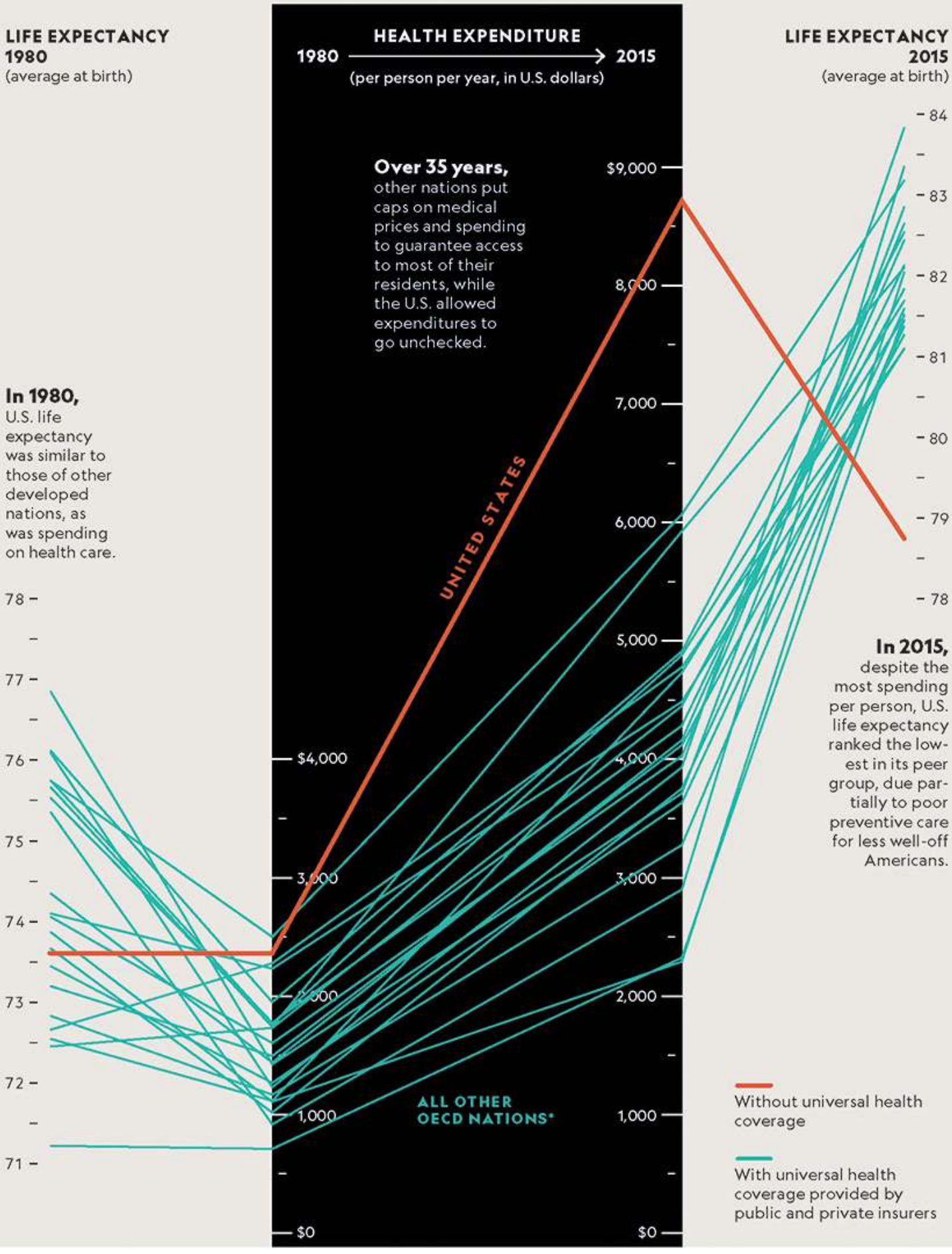
What to Eat When: A Strategic Plan to Improve Your Health & Life Through Food, published by National Geographic Books, is available December 31, 2018, where books are sold and at *shopng.com/books.*

PHOTO: MARK THIESSEN

OUTCOME VS. COST: GLOBAL HEALTH CARE

FROM HIGH-TECH SURGERIES to groundbreaking HIV treatments, medical innovation has dramatically improved health outcomes since the 1980s. In wealthy nations, health care spending has risen, and lives have been lengthened. But the United States follows a slightly different pattern, with skyrocketing health expenditures and a much slower increase in life expectancy. Unequal access to treatment and poor preventive care for many U.S. residents may partly explain the difference, analysts say.

BY **ALBERTO LUCAS LÓPEZ** AND **RYAN T. WILLIAMS**



*INCLUDES ONLY OECD COUNTRIES FOR WHICH DATA ARE AVAILABLE. THE OECD IS A GROUP OF 36 OF THE WORLD'S MORE AFFLUENT, DEVELOPED NATIONS.
SOURCES: ESTEBAN ORTIZ-OSPINA, *OURWORLDINDATA.ORG,* OXFORD UNIVERSITY; UN POPULATION DIVISION; OECD.STAT

HOW CAN WE FARM BETTER?

Beneath the soil, hidden from human eyes, a disease infects the roots of a crop. Sensors detect the change, drones identify the affected plants, Artificial Intelligence processes the data, miniature robots take action, and within a few hours a disaster is averted.

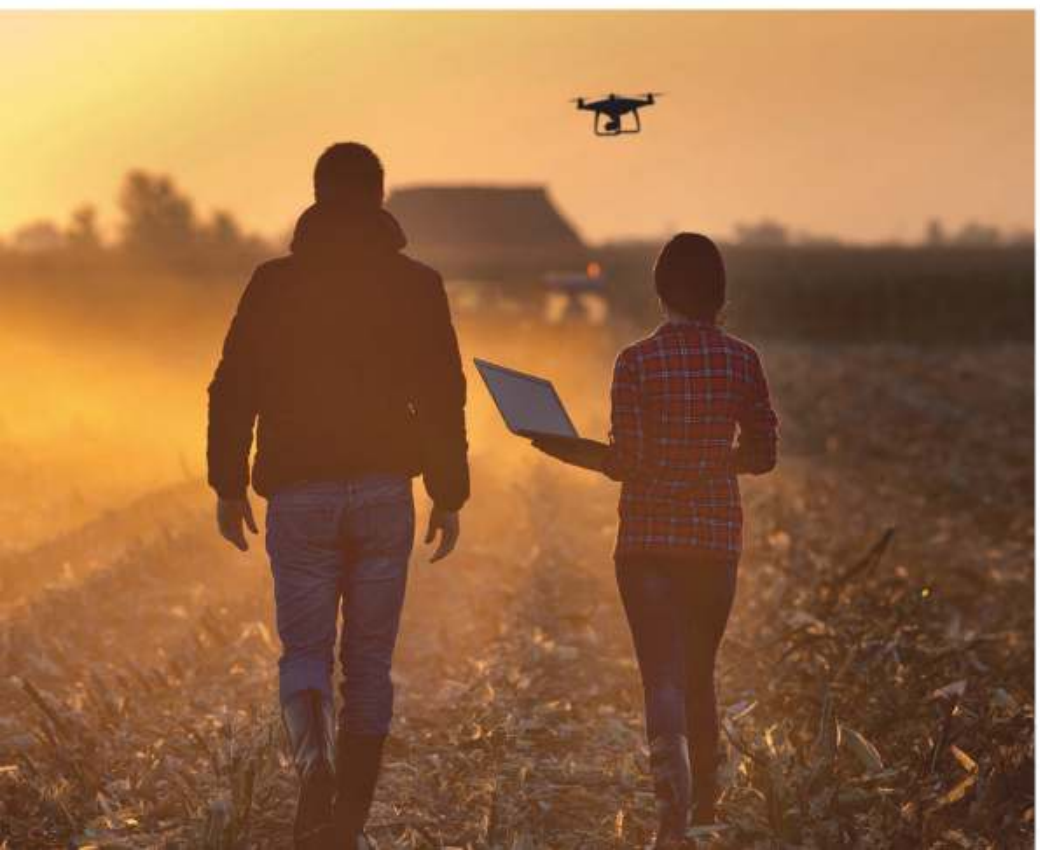
This could be the future of farming.

For more than 12,000 years the tools of farming have evolved from hoes to horse-drawn plows to high-tech tractors. Now, as we face the unprecedented challenge of feeding eight billion people, the tools of agriculture are changing once again.

A drone hovering high above the countryside gives a farmer both a holistic overview and a granular insight into what is happening on their land. Relatively easy to deploy and equipped with an array of specialist cameras, drones provide real-time data on crops, pinpointing areas that need watering, weeding, or treating, and even performing some of those tasks themselves. Similarly, drones can track herds of livestock over vast areas, helping to identify sickness and locate lost animals more efficiently than man alone.

Meanwhile, on the ground, autonomous robots designed to drill, sow, water, weed, treat, and even harvest crops, could be the key to micro-managing large areas of farmland. These robots work as a team, communicating constantly with one another while independently making precise decisions on exactly what is needed centimeter by centimeter.

SUCH LARGE-SCALE, PRECISION AUTOMATION HAS THE POTENTIAL TO SIGNIFICANTLY REDUCE WASTE AND TO INCREASE YIELDS ACROSS SOME OF THE MOST LABOR-INTENSIVE ASPECTS OF FARMING.



Alongside drones and robots, a combination of sensors, hand-held devices, apps, and wearables, are making it easier to gather valuable information on everything from soil health to crop growth to the welfare of individual animals. All this technology, once mastered, could enable farmers to take even more targeted and timely action across even larger areas of land—significantly boosting efficiency. Armed with these new tools, farmers will have greater control of their resources than ever before, at a time when maximizing agricultural productivity has become a global priority.

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NATIONAL GEOGRAPHIC PHOTO ARK

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The Immortal Corpse P. 68

Every Body Is Unique P. 42

At the vanguard of human health, scientists tweak genes to create precision medicine, and a body donated to science becomes a holographic virtual cadaver. Meanwhile a new generation embraces ancient Chinese remedies—and the United States posts one of the developed world's highest rates of pregnancy-related deaths. Where does all this lead?

The Secrets of Chinese Medicine P. 96

The Truth About Maternal Mortality P. 122

THE FUTURE OF MEDICINE

BIONIC PROSTHETIC

A bionic eye sounds like science fiction, but a 3D printer created this prototype in an hour, bringing the promise of a seeing prosthetic that much closer to reality. –MORE ON PAGE 28

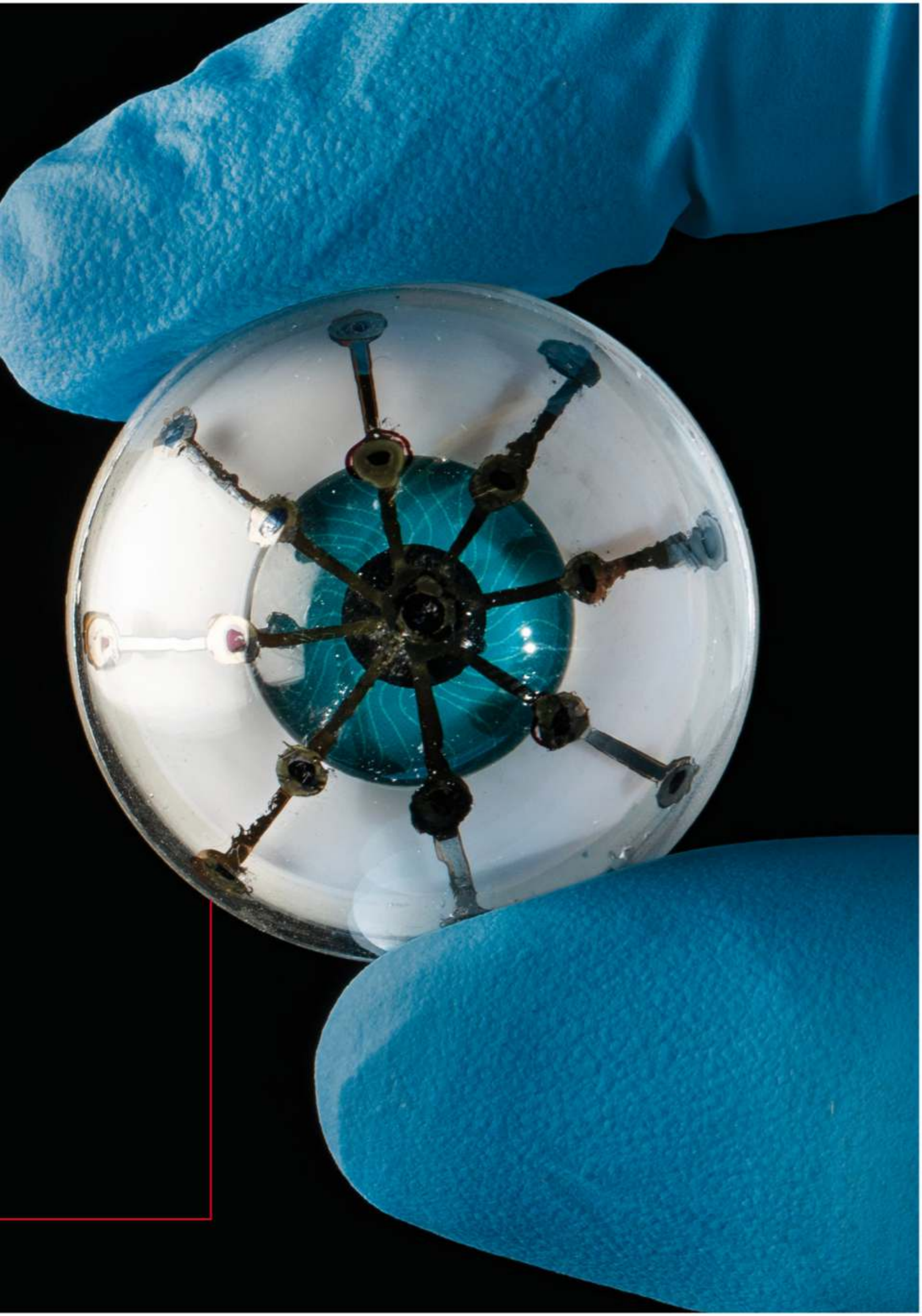

PHOTO: REBECCA HALE, NGM STAFF

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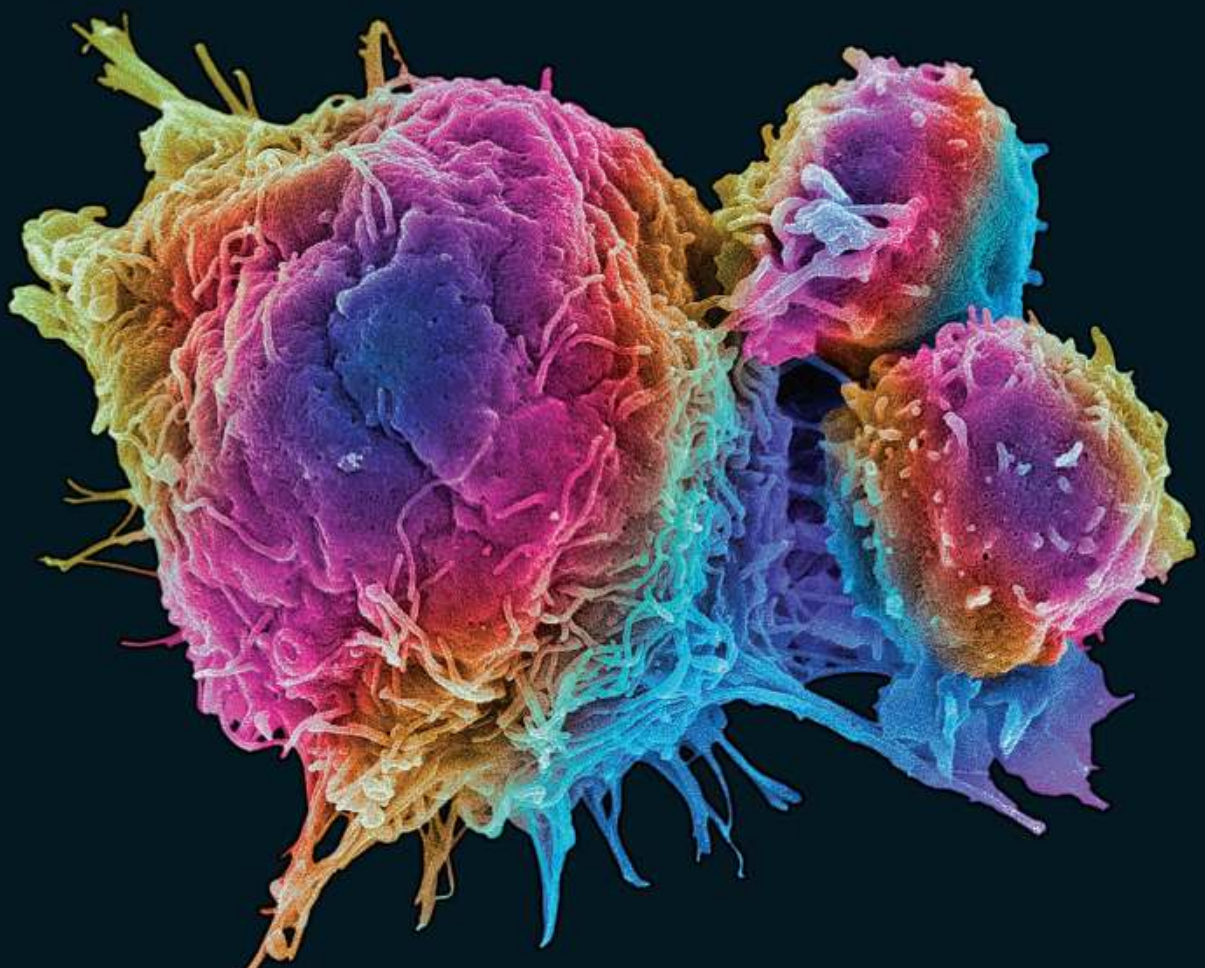
Cancer Cells



We're not saying all viruses are good, just the ones that kill cancer.

America's biopharmaceutical researchers are discovering new ways to fight cancer by injecting it with a genetically modified virus. In a sense, they figured out how to give cancer itself a fatal illness.

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THINK OF IT: EVER PRESENT, ANALYTICS-ENABLED, INDIVIDUALIZED ATTENTION TO YOUR WELL-BEING, WITH A FOCUS ON PREVENTION.

BY **DANIEL KRAFT**

I WOULD NEVER have met Harriett were it not for our mutual friend, Linda. I’m a physician in Northern California; Harriett’s a communications executive in New York City. Linda co-founded an online personal genomics company, to which Harriett and I each sent our genetic information for analysis.

Linda introduced us after she saw that Harriett and I had something in common: a rare type of mitochondrial DNA, which meant we were distantly related. It turns out that we also share that genealogy with a prehistoric celebrity: Ötzi the Iceman, whose 5,300-year-old frozen corpse was discovered in the Alps in 1991. For fun, I even started a Facebook group for people with the same DNA variant as Ötzi and Harriett and me.

I tell this story to make a point. Harriett and I met over a feat of biomedical science—mass-market, low-cost gene analysis—that once was unimaginable and now is commonplace. The convergence of digital

ON PAGE 24

Blink and There'll Be a Bionic Eye

Building a bionic eye has many challenges, but researchers may have just solved one of them: Using 3D technology, they printed an array of light receptors on a glass eye-shaped object. The silver particles they used as "ink" stayed put, despite the curved surface, and the photodiodes converted light into electricity with 25 percent efficiency. Next step: More light receptors and a softer surface to make the implant more comfortable. –RACHEL HARTIGAN SHEA

INFORMATION

An Explosion of Health Data

Just how fast is the growth of health-related data? A report from the Stanford University School of Medicine put it this way: "The sheer volume of health care data is growing at an astronomical rate: 153 exabytes (one exabyte = one billion gigabytes) were produced in 2013 and an estimated 2,314 exabytes will be produced in 2020, translating to an overall rate of increase [of] at least 48 percent annually."

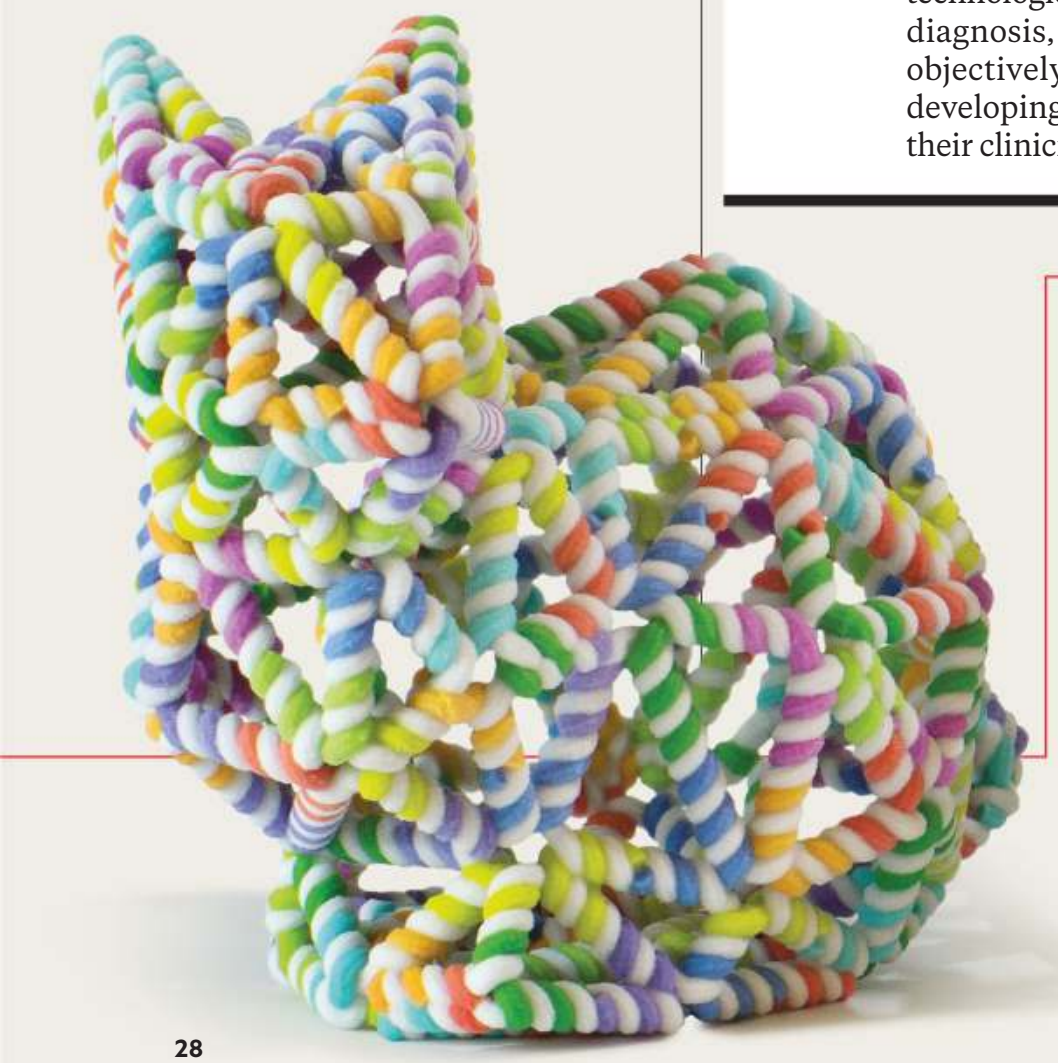
technologies and social platforms made it possible for us to learn our genotypes and share what we found out with the online universe.

Since then, we've seen an explosion of tech-driven gains and innovations that have the potential to reshape many aspects of health and medicine. All around us, technologies from artificial intelligence (AI) to personal genomics and robotics are advancing exponentially, giving form to the future of medicine.

The innovations I describe here—many of which are still in early stages—are impressive in their own right. But I also appreciate them for enabling the shift away from our traditional compartmentalized health care toward a model of "connected health." We have the opportunity now to connect the dots—to move beyond institutions delivering episodic and reactive care, primarily after disease has developed, into an era of continuous and proactive care designed to get ahead of disease. Think of it: ever present, analytics-enabled, real-time, individualized attention to our health and well-being. Not just to treat disease, but increasingly, to prevent it.

IN THE OLD MODEL OF MEDICINE, patients' health data was collected only intermittently, primarily in clinic visits, and scattered among paper files and siloed electronic medical record systems. Today there's a far better option: personal technology that can monitor vital signs continuously and record health data comprehensively.

Just a decade after the first Fitbit launched the "wearables" revolution, health tracking devices are ubiquitous. Most are used to measure and document fitness activities. In the future these sensing technologies will be central to disease prevention, diagnosis, and therapy. They'll measure health objectively, detect changes that may indicate a developing condition, and relay patients' data to their clinicians.



NANOSCIENCE

Useful DNA Origami

Bioengineers have made nanoscale tetrahedrons, bunnies, and more by folding DNA into origami. They enter the desired shape into an algorithm that determines how to bend a long DNA strand, or scaffold, into two- and three-dimensional shapes held together by shorter DNA pieces. Other molecules studded along the scaffold's surface give it its function, like ferrying medicine or gene editing tools to a particular part of the body. MIT's Mark Bathe says the "holy grail" of DNA origami would be a structure that can cross the blood-brain barrier that now keeps many drugs from reaching the brain.
–THERESA MACHEMER

PHOTOS, FROM TOP: REBECCA HALE, NGM STAFF; ERIK BENSON AND BJÖRN HÖGBERG, KAROLINSKA INSTITUTET


Some things are
bigger than banking
(Like coloring outside the lines.)
You like doing things your own way. We get that. That's why with Regions LockIt,SM you can use your Regions mobile app to customize your card protection, so if your card gets lost or stolen, you can lock your cards before you even report the problem. So go ahead. Paint your self-portrait, and enjoy peace of mind with LockIt.
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LENS TEST

Keeping an Eye on Health

Forget the finger-prick blood test. The race is on to create contact lenses that track glucose levels from tears. South Korean researchers have been able to attach transparent, flexible electronics that won't block vision while wirelessly relaying electricity to run glucose sensors. –EVE CONANT

GASTRO ORIGAMI

Robot Unfolds, Goes to Work

A new wrinkle in origami robots is rectangular, packs a tiny magnet, and folds accordion-style to fit in a pill-size case perfect for swallowing. Now in testing, the robot unfurls in the gut to grab and remove an ingested button battery or patch tissue harmed by its presence. –LORI CUTHBERT

WEAR IT

A Patch That Reads Deep

This wearable patch, smaller than a postage stamp, keeps the beat—heartbeat, that is. It measures blood pressure deep within the body by emitting ultrasonic waves that pierce the skin and bounce off tissues and blood, feeding data back to a laptop. –EC

Flexible, electronic medical tattoos and stick-on sensors can take an electrocardiogram, measure respiratory rate, check blood sugar, and transmit results seamlessly via Bluetooth. It's mobile vital sign tracking, but at a level once found only in an intensive care unit.

Hearing aids or earbuds with embedded sensors will not only amplify sound but also track heart rate and movement. Such smart earpieces also could be integrated with a digital coach to cheer on a runner, or a guide to lend assistance to dementia patients.

Smart contact lenses in the future will be packed with thousands of biosensors, and engineered to pick up early indicators of cancer and other conditions. Lenses now in development may someday measure blood sugar values in tears, to help diabetics manage diet and medications.

Implantable devices may include a radio-frequency ID chip under the skin that holds a patient's medical records, or a subcutaneous sensor that could continuously monitor blood chemistry. Ingestible devices in capsules will deploy once swallowed to perform tasks in the gastrointestinal system, from delivering treatment to isolating foreign objects.

A monitoring patch on a pregnant woman's belly can detect uterine muscle movement, the better to know when labor is progressing. Later, parents can keep a digital eye on their infant via a baby cam that charts the infant's respiration on the screen and sends an alert if the baby stops breathing. There's even high-tech help for developing preemies: headphones play music calibrated to soothe or stimulate, and scans check brain waves to see whether it's working.

And if we want to collect health data when no one's wearing a device? Engineers at MIT have modified a WiFi-like box so it can capture vital signs and sleep patterns of several people in the same residence.

As new sensing technologies emerge, they'll yield more biomedical data and insights—and these can be paired with growing stores of genomic data. In combination, they'll lead us to new ways to optimize wellness, understand disease, and select the most patient-specific preventives and interventions.

THE WIDENING ARRAY of digital tools paired with AI analytics almost certainly will boost diagnosticians' accuracy and speed, improving disease detection at early stages and thus raising the odds of successful treatment or cure. Many likely will be phone-based.

With smartphone otoscopes, parents can look in kids' ears and share the view with a pediatrician. Apps and sensors can enable a phone to take electrocardiograms to check for dangerous arrhythmias; software and a microphone can equip it to "listen" to a cough and diagnose pneumonia. To improve treatment of hypertension—a leading risk factor associated with early death—sensors now in development would take continuous blood pressure readings (no cuff needed).

Some technologies dramatically enhance the accuracy and speed of clinicians' efforts. Identifying a

PHOTOS, FROM TOP: KIM KYOUNG CHAE, UNIST; JASON DORFMAN, MIT CSAIL; CHONGHE WANG AND SHENG XU, UC SAN DIEGO

POSTNATAL CARE

A MUSICAL MILESTONE

BABIES BORN PREMATURELY CAN SUFFER MULTIPLE SETBACKS. A PIONEERING MUSIC PROJECT MAY HELP THEM FLOURISH.

In most nations, premature births—at or before 37 weeks—have risen in the past 20 years. Leaving the nourishing confines of the womb too early can result in complications and often leads to a stay in a hospital's neonatal intensive care unit (NICU).

At University Hospital in Geneva, Switzerland, music is folded into the care plan for some preemies. But unlike other NICU music programs, this novel project features three specific songs, which babies listen to through special headphones made for tiny, fragile heads. The songs are part of an ongoing study that aims to understand how music affects a preterm newborn's brain and how well it can recognize melody, tempo, and pitch—skills likely related to language processing.

Developed by neonatologist Petra Huppi, researcher Manuela Filippa, and composer Andreas Vollenweider, the project involves scanning babies' brains via MRI as they listen and comparing the scans to those of babies who were not exposed to the music. The songs—short and "much simpler than Mozart," says Huppi—were composed to help the infants fall asleep, wake up, or interact.

Further research will assess the full benefit of this therapy, but early findings are promising. MRI scans reveal improved brain connectivity, and the songs appear to support the daily rhythm of sleeping and waking—key to thriving in a noisy NICU and the world beyond. —CATHERINE ZUCKERMAN

PHOTO: CRAIG CUTLER

'ELECTROCEUTICALS'

Power Therapy for the Brain

The use of electricity as medicine has come far since the first cardiac pacemaker. Implanted electrodes, visible in this x-ray, deliver electric pulses known as deep brain stimulation (DBS). These "brain pacemakers" have effectively treated conditions including obsessive-compulsive disorder and Parkinson's disease and are being tested in Alzheimer's patients to improve focus, memory, and judgment. A Cleveland Clinic study of DBS to spur stroke recovery has shown promising results. A 2015 stroke robbed a patient of function on her left side—but after months of physical and occupational therapy and DBS, she plays catch with her grandkids and even threw the opening pitch at a Cleveland Indians game. –PATRICIA EDMONDS

bacterial or viral infection, and the best drugs to treat it, can mean long waits for blood cultures. But scientists have developed biochips that can do a complete microbial scan in a couple of hours, without culturing—and in the process may identify mutations that make some microbes antibiotic resistant.

The boom in research into the human microbiome—the trillions of bacteria on and in each individual's body—is encouraging new modes of diagnosis and increasing understanding. Genetic analysis could help unlock the many secrets of the gut microbiome, believed to play a role in the risk and development of obesity, inflammatory bowel disease, cardiovascular disease, and even neurologic conditions.

Thanks to artificial intelligence and machine learning, diagnostic tools can be trained to read tissue samples and radiologic scans. Google researchers fed more than a quarter-million patients' retinal scans into algorithms that recognize patterns—and the technology "learned" to spot which patterns predict a patient has high blood pressure or is at increased risk for heart attack or stroke. In some comparisons, digital tools produced more accurate analyses than did human pathologists, dermatologists, or radiologists.

IN THE UNITED STATES, the days of doctors routinely making house calls are long gone. Soon to follow: the practice of most medical care occurring in person in a practitioner's office, a clinic, or a hospital. Increasingly, care will be delivered in a blended, real-world-mixed-with-virtual-world model.

The majority of patient-doctor interactions don't require the "laying on of hands," or a physical exam. Private (and increasingly reimbursable) Skype-like interactions between patient and physician will take

SELFIE DIAGNOSTICS

Reading the Whites of Our Eyes

A smartphone app in development at the University of Washington could help diagnose pancreatic cancer by checking the whites of the eyes for signs of jaundice. Snap a selfie and the app would use it to spot elevated bilirubin levels, a possible sign of the disease. –LC

PHOTOS, FROM TOP: OHIO STATE UNIVERSITY WEXNER MEDICAL CENTER; REBECCA HALE, NGM STAFF

NEW STYLE FOR THE NEW AIRPORT

TURKISH AIRLINES

WIDEN YOUR WORLD

PROSTHETICS

3D PRINT REMEDIES

THOUSANDS OF PEOPLE LOSE LIMBS EVERY YEAR. LOW-COST TECH COULD HELP THEM.

Many artificial limbs still begin with a plaster cast. Transforming that mold into a socket that comfortably fits the residual limb is an expensive and halting process—if you're lucky enough to live near a trained prosthetist. Many amputees worldwide don't have access to prosthetic limbs. Mobile phones and 3D printing may offer a solution, says Albert Yu-Min Lin, a National Geographic explorer who lost part of his leg in 2016. Phone cameras could scan residual limbs, providing measurements to professionals with 3D printers, who would produce matching low-cost sockets to be shipped to amputees all over the world.

–CHRISTINA NUNEZ

See Albert Lin, shown here at Arizona's Antelope Canyon, on the TV series Explorer. It returns with new episodes on January 7 at 10/9c on National Geographic.

PHOTO: BRUNA BORTOLATO

THE PRESCRIPTIONS IN YOUR FUTURE COULD BE DOLED OUT BY AN ATM-LIKE ROBOT, REMOTELY CONTROLLED BY A PROVIDER OR ALGORITHM TO ENSURE THE RIGHT DOSES AT THE RIGHT TIMES.

place through web-based portals. Patients' vital signs will be obtained and shared with the physician via web-integrated wireless scales, blood pressure cuffs, and monitoring devices. A telemedicine dermatologist can use the selfie you've sent to prescreen your suspicious-looking skin spot and tell you either to rest easy or get it checked in person.

The time it usually takes for medical appointments—including travel and waiting room time—will plummet, supplanted by telemedicine visits with a new type of clinician, the "virtualist." The provider-patient relationship will take a déjà vu turn, with patients in their own homes for appointments.

In the future your prescriptions may include more "digiceuticals." Already in limited use, they're meant to enhance well-being or manage a condition with no drugs, no in-person ministrations—just use of prescribed software, or digital exchanges with a practitioner offering information and encouragement.

Though many are still under study, some digiceuticals are demonstrating effectiveness. Examples: At least two firms have developed apps to reduce the relentless noise of tinnitus by retraining the brain to turn down the volume—and some reviewers say it works. To manage heart failure patients, the Mayo Clinic prescribed the use of an app that would track blood pressure, activity, and other factors. The reported result: a 40 percent reduction in hospital readmissions related to cardiac issues.

The conventional prescriptions in your future could be doled out by an ATM-like robot, remotely controlled by a provider or algorithm to ensure the right doses at the right times. Or your clinician could consult your genetics test to determine the most appropriate drugs for your specific gene profile.

A few months ago, Harvard and MIT scientists found a way to much more accurately forecast an individual's risk score for five deadly diseases. They achieved this by looking at DNA changes at 6.6 million locations in the human genome and applying a sophisticated algorithm. But even genetic tests that analyze only parts of the genome—like the one I took—can provide valuable information about predisposition to dementia, Parkinson's disease, diabetes, and other conditions. Yet again, advances in medical technology may hold benefits for me, and for Harriett. (Sorry, Ötzi.)

If you're not meeting in person with your practitioner, could a robot serve as well as a human? Soon

AUGMENTED, VIRTUAL REALITY

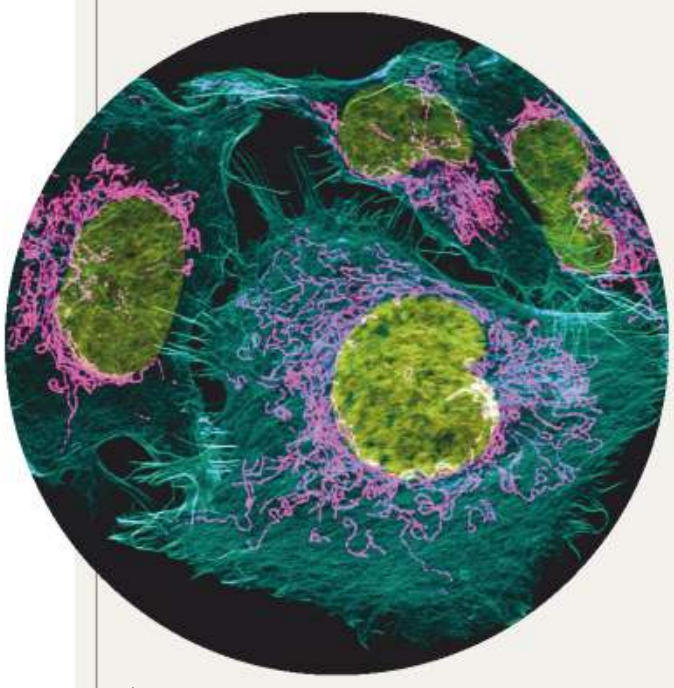
Bending Reality to Medical Uses

Augmented and virtual reality (AR and VR) are moving from the gaming world to the medical school, clinic, and operating room. Nursing and medical students can learn anatomy and physiology on VR tours of human organs. Operations recorded or live-streamed in VR let far-flung students observe from the vantage of surgeons. VR therapy leverages the intense, immersive experience to treat pain, phobias, and other conditions. AR can blend imaging data with actual procedures, so a surgeon at work can see into a body or be guided by a remote mentor. –DK

GENETIC TOOLS

Better Prostate Cancer Analysis

High-grade prostate cancers can be lethal, low-grade cases may need only monitoring—and both may benefit from recent advances at the Cleveland Clinic. One research team found that patients with a testosterone-based genetic anomaly had different responses to certain drugs, which could open the way to personalized treatments. Other researchers developed a new blood test that predicts prostate cancer risk more accurately than existing tests; it could dramatically reduce the need for biopsies and the treatment of cases unlikely to be lethal. –PE



Fluorescence delineates the parts of these prostate cancer cells.

THREE-COLOR CONFOCAL IMAGE: JAMES HAYDEN, WISTAR INSTITUTE

NOTICE OF SETTLEMENT

For Owners of Property On Which IKO Organic Asphalt Roofing Shingles Are Installed

What Is The Litigation About? In this Litigation, *In re: IKO Roofing Shingle Products Liability Litigation*, MDL Docket No. 2104, filed in the U.S. District Court for the Central District of Illinois, the Named Plaintiffs (representatives of owners of buildings on which IKO organic shingles (the "Shingles") were installed) alleged that the Shingles were defective or failed to perform as promised. The IKO Defendants deny these allegations. In 2018, the IKO Defendants and the Named Plaintiffs reached a proposed class action settlement to resolve this dispute, subject to the Court's approval. Further information about this Litigation and related settlement is available in the long form Notice Of Proposed Settlement In Class Action, the Agreement Of Compromise And Settlement ("Settlement Agreement"), and other documents, located on the settlement website at www.IKOOrganicRoofingShinglesClassActionSettlement.com.

What Shingles Are The Subject of this Litigation? The Shingles that are the subject of this Litigation are organic asphalt roofing shingles that were manufactured by IKO and sold throughout the United States primarily between 1978 and 2008, including but not limited to the following: Aristocrat, Aristocrat (Imperial), Armour Plus, Armour Plus 20, Armour Seal, AM Armour Seal, Armour Seal Supreme, Armour Seal (Metric), Cathedral XL, Crowne 30, Imperial Seal, Imperial Superplus, Seville, Superplus, AM Superplus, Superseal, Supreme, Royal Victorian, Total, New Englander, Quantum Skyline, Vista, Renaissance, Renaissance XL, Armour Lock, Armour Tite, Superlock, Suretite, Ultralock, Ultralock 25, Chateau, Chateau Ultra Shadow, and Harvard.

Who Is Involved? To receive the benefits under this settlement, you must be a Settlement Class Member. You are a Settlement Class Member if as of the date of the Settlement Agreement you own or owned a home, building, or other structure located in the United States upon which the Shingles were installed.

What Are the Settlement Terms? In summary, the IKO Defendants agree to extend existing (non-expired) Shingle warranties by five years; provide new Shingle warranties for five years after the date of expiration for warranties that expired five or fewer years prior to the date of the Settlement Agreement; limit the payment reduction factor on the final year of Shingle warranties; clarify their Shingle warranty claims procedures, including the language of goodwill releases; and, provide Settlement Class Members who submit valid Shingle warranty claims the option of selecting cash payments or replacement fiberglass shingles of equal or greater value. Class Counsel will move at the Final Approval Hearing for an award of fees, costs, and service awards, not exceeding $7,500,000.

If I Am A Member of the Class, What Are My Legal Rights? EXCLUDE YOURSELF. If you exclude yourself (or "opt out"), you are not eligible for any benefits under the Settlement Agreement. To opt out you must send a complete and timely Request for Exclusion to the Notice Provider. For instructions on excluding yourself from the settlement, see the long form Notice Of Proposed Settlement In Class Action. The deadline for excluding yourself is February 20, 2019. **OBJECT**. If you do not exclude yourself from the settlement but think some aspect of the proposed settlement is unfair, you can write to the Court about why you do not like the settlement. To do so, you must send a statement of your objection to the Court, Class Counsel, and the IKO Defendants' counsel. For instructions on objecting to the settlement, see the long form Notice Of Proposed Settlement In Class Action. The deadline for objecting is February 15, 2019. **APPEAR AT A HEARING**. If you do not exclude yourself, you can ask to speak to the Court about the fairness of the settlement. The Court will hold a Final Approval Hearing to decide if the proposed settlement is fair, reasonable, and adequate on March 13, 2019. The hearing will be held at: United States District Court for the Central District of Illinois, 204 U.S. Courthouse, 100 N.E. Monroe Street, Peoria, IL 61602. You may, but need not, enter an appearance at the hearing through your own counsel at your own expense. For instructions on appearing at the Final Approval Hearing, see the long form Notice Of Proposed Settlement In Class Action. The deadline for filing paperwork to appear at the hearing yourself or through counsel is February 15, 2019. **DO NOTHING**. If you do nothing, you will receive the benefits of the settlement and will be bound by the terms of the settlement and give up your right to sue IKO and other Released Persons on these claims, even if you have other claims, lawsuits, or proceedings pending against IKO involving alleged damage to the Shingles during the Class Period. For more information on your rights under the proposed settlement, write to the Notice Provider at *In Re IKO Roofing Shingles Products Liability Litigation* Notice Provider, P.O. Box 404000, Louisville, KY 40233-4000.

PLEASE DO NOT CALL THE COURT.

Let there be internet

Valley_of_the_BOOM

A Six-Part Limited Series

SUNDAY JAN 13 9/8C

NATIONAL GEOGRAPHIC

Legal Notice

If between November 16, 2005 and April 29, 2010 you checked a bag on a domestic flight with US Airways, your bag was lost or delayed, and between November 16, 2005 and April 29, 2010 you reported to US Airways that your bag was lost or delayed and did not receive a refund of the checked baggage fee for the lost or delayed bag, you could receive a cash payment from a class action settlement.

Para obtener una notificación en español,por favor llame o visite nuestra web.

A settlement has been proposed in a class action lawsuit alleging that US Airways failed to deliver checked baggage on domestic flights within a particular timeframe. US Airways denies that it did anything wrong or unlawful, and specifically denies that it agreed to deliver passenger baggage in a particular timeframe. The Court did not rule in favor of either party. The U.S. District Court for the Northern District of California authorized this notice. Before any money is paid, the Court will have a hearing to decide whether to approve the settlement.

Who Is Included? All passengers of US Airways who traveled on a domestic flight between November 16, 2005 and April 29, 2010, checked baggage that was lost or delayed, reported to US Airways during the Class Period that their checked baggage was lost or delayed, and whose checked baggage fee was not previously refunded.

What Does The Proposed Settlement Provide? The settlement provides a $9.85 million Settlement Fund to pay (i) on a *pro rata* basis, money to Class Members whose current address is able to be determined based on US Airways' records and other sources, and who either (a) appear in US Airways' records as having, during the Class Period, checked a bag on a domestic flight with US Airways that was lost or delayed, reported to US Airways that his or her checked baggage was lost or delayed, and not received a refund of the checked baggage fee for the lost or delayed bag or (b) prior to the Claim Deadline submits a valid Claim Form and attests under penalty of perjury pursuant to 28 U.S.C. § 1746 that he or she checked a bag with US Airways on a domestic flight between November 16, 2005 and April 29, 2010 that was lost or delayed, reported to US Airways during the Class Period that his or her checked baggage was lost or delayed, and did not receive a refund of the checked baggage fee for the lost or delayed bag, and (ii) Settlement Administration Expenses, an Incentive Award to the Class Representative, and Attorneys' Fees and Expenses.

Who Represents You? The Court appointed the law firms Foley Bezek Behle & Curtis, LLP, Karczag and Associates PC, and the Law Office of William M. Aron to represent you as "Class Counsel."

What Are Your Options? If you are a Class Member, you may: exclude yourself from the class; or do nothing and be bound by the terms of the settlement; send in a Claim Form; object to the settlement; and/or go to a hearing about the fairness of the settlement.

If you do not want to be legally bound by the settlement, you must exclude yourself by **February 21, 2019**. If you exclude yourself, you cannot receive a cash payment from this settlement, but you can sue, or continue to sue, US Airways regarding the claims in this case.

If you do not exclude yourself from the Class, you may submit a Claim Form and/or object to the settlement by **February 21, 2019**.

The Court will hold a hearing in this case on **April 1, 2019** at **10:00 a.m.** in Courtroom 2 of the San Jose Courthouse, 280 South 1st Street, San Jose, California 95113. At this hearing, the Court will consider whether to approve: the settlement, Class Counsel's application for Attorneys' Fees up to $2,955,000 and expenses up to $50,000, and an Incentive Award up to $10,000. You or your attorney may appear at the hearing, but you do not have to.

Class Counsel's application will be available on the Settlement Website after they are filed and before the hearing.

Want More Information? Full details, including the detailed notice, which explains how to exclude yourself or object, Claim Forms and the settlement agreement, are available at www.checkedbaggagesettlement.com, by calling 1-844-798-9819, or by writing to H*ickcox-Huffman v. US Airways, Inc*. Settlement Administrator, P.O. Box 404000, Louisville, KY 40233-4000.

DO NOT CONTACT THE COURT or US Airways or its affiliates (including American Airlines, Inc.) concerning this notice or this lawsuit.

www.checkedbaggagesettlement.com
1-844-798-9819

they may be answering information and triage calls. A chatbot nurse will try to learn what ails you by asking about your symptoms and tapping into data from your wearable devices and the crowdsourced health records of others like you. Should your complaint be psychological more than physical, you can seek counseling from a virtual therapist programmed to converse as a human would, offer self-help guidance, and lend a sympathetic ear.

Robots may participate in care during face-to-face encounters as well. Consider the robotic phlebotomist, equipped to ultrasonically confirm which vein is the best target, then draw blood or insert an IV. In countries short on human caregivers, caretaker robots may be employed to lift and move patients, as well as interact socially. And robots programmed as physical therapy coaches can help patients stick with their exercise regimes.

IT'S GREAT TO BENEFIT from all this technological progress, but it's just as important to spread it. In 2016 an estimated 3.6 million people in low- and middle-income countries died because they lacked access to health care. And even more people in those countries—an estimated five million—died because they got poor-quality care. We can change that, starting today, by sharing the wealth of new medical technologies and other health and wellness resources. □

Daniel Kraft is a physician-scientist trained at Stanford and Harvard. He serves as faculty chair for medicine at Singularity University and is founder and chair of Exponential Medicine, a program that explores the convergence of accelerating technologies and their implications for the future of health care.

AI ANALYSIS

The Sharp Eyes of AI

Correctly identifying the cancer cells in a lung tissue sample (below left) is key to successful treatment. It's also an ideal diagnostic use of artificial intelligence. In one study, the same AI that Google uses to identify objects online was trained to recognize forms of cancer. It then found two forms in a tissue sample (below right) as accurately as a human could, in seconds. AI also has been used to model the precise dosage of a cancer drug to shrink tumors but cause minimal toxic side effects. –LC

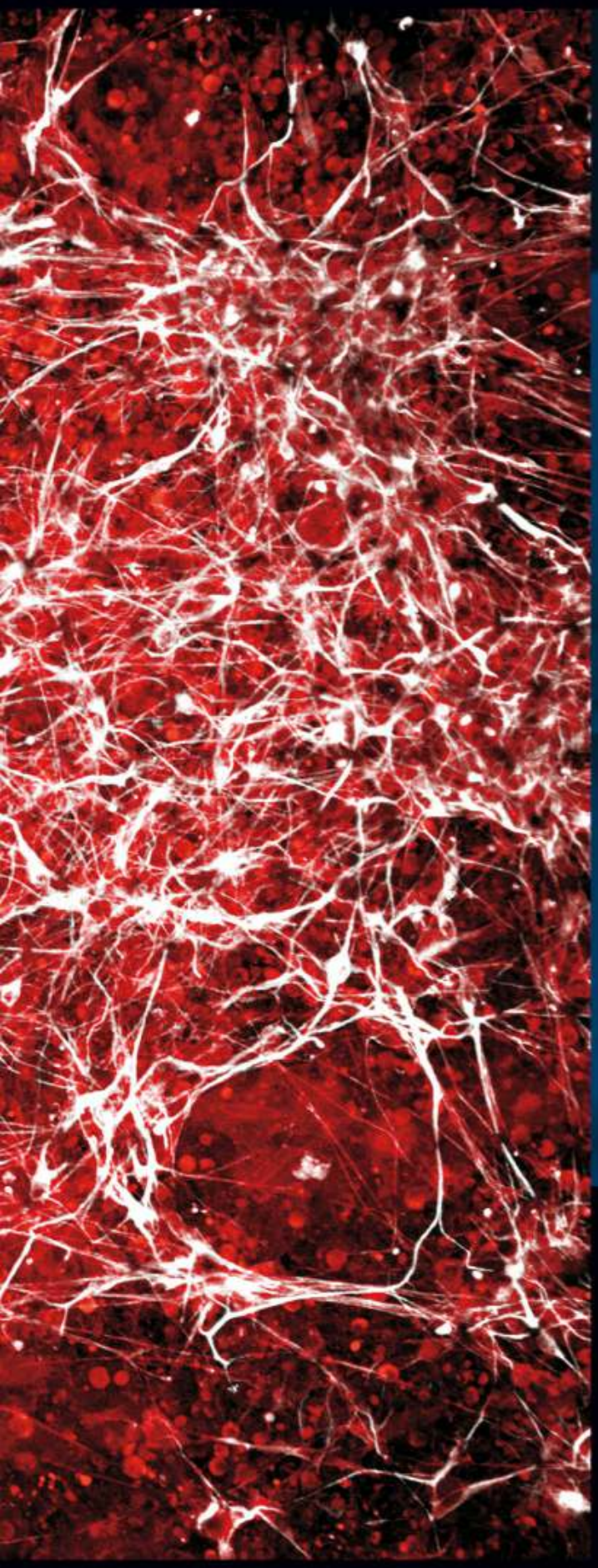
For the sample at left, AI produced the analysis at right, showing normal lung tissue (gray) and two forms of cancer: adenocarcinoma (red) and squamous cell carcinoma (blue).

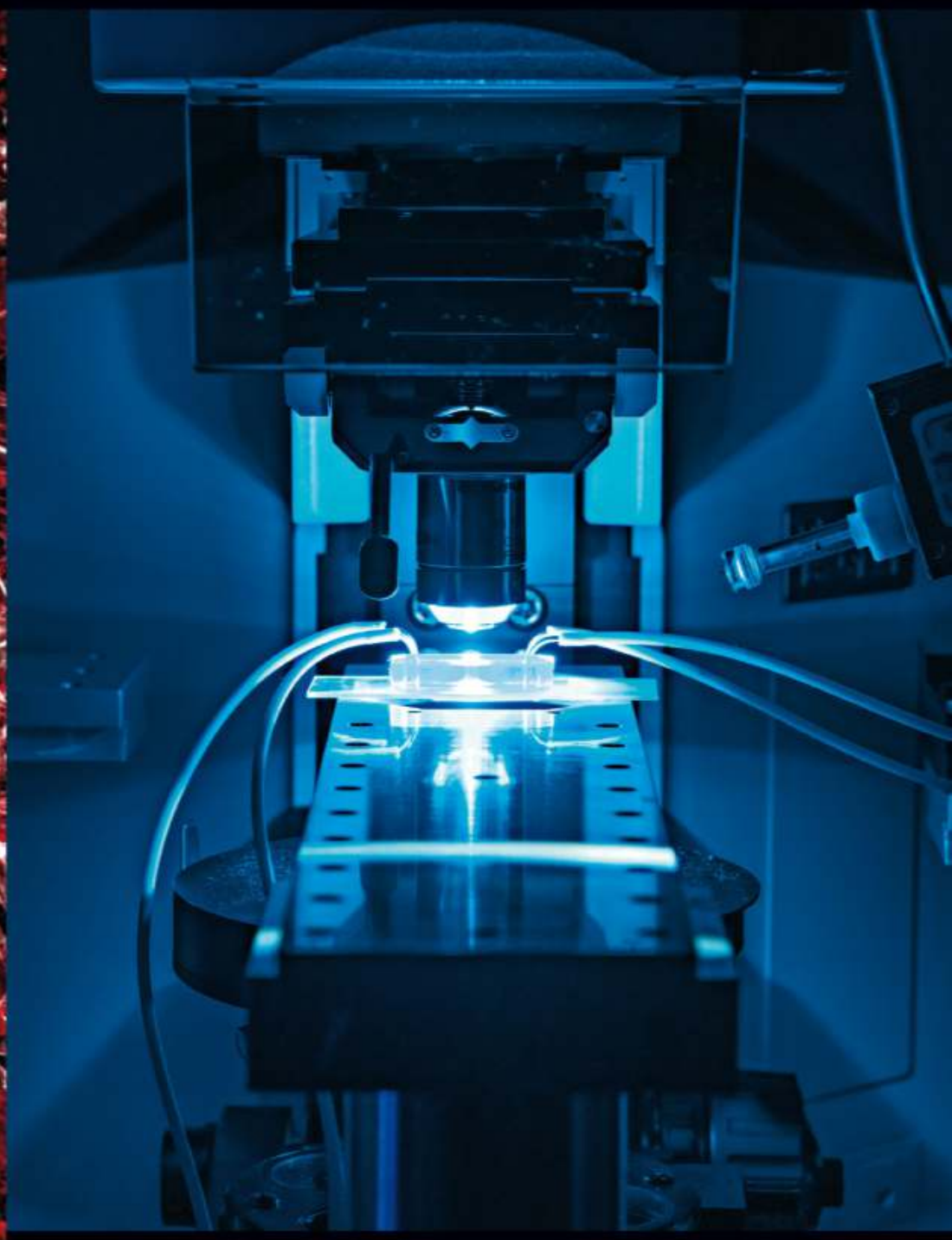
REGAINING MOBILITY

Robotic Support

For patients with severe mobility problems such as partial paralysis, scientists are developing robotics that enfold and support like an exoskeleton. The devices are programmed to guide the body through motions—such as helping a stroke victim walk—that can rebuild posture and strength. –NATASHA DALY

FROM TOP, TISSUE IMAGE: CANCER GENOME ATLAS; HEAT MAP: NICOLAS COUDRAY, NYU SCHOOL OF MEDICINE; PHOTO: MARCEL VAN DEN BERGH





PATIENT ORGANS IN MINIATURE

On this chip shown actual size, researchers Clive Svendsen and Samuel Sances at Cedars-Sinai in Los Angeles, California, micro-engineered spinal cord tissue from a patient with amyotrophic lateral sclerosis. Motor neurons (white) and a blood vessel (red), derived from the ALS patient's stem cells, form functioning tissue, as revealed in this enlarged image (background). Using a microscope (above), the scientists can observe neurons firing in real time or take pictures to analyze later. Their aim is to create chips that will be able to predict how different drugs will work for an individual patient.

LEFT, COMPOSITE: CRAIG CUTLER (HAND WITH CHIP); SAMUEL SANCES, CEDARS-SINAI (BACKGROUND)

A new era of health care is coming.
PRECISION MEDICINE
**will monitor our health moment to moment,
predict our risk of cancer,
heart disease, and other ailments—
and devise treatments tailored
to each of us.**

EVERY BODY IS UNIQUE

BY FRAN SMITH
PHOTOGRAPHS BY CRAIG CUTLER

A MOTHER'S VOICE

Cristina Iossa sings to her prematurely born son, Alessandro, at the neonatal intensive care unit of University Hospital in Modena, Italy. In NICUs, parents are now a more frequent presence. "The mother's voice to her offspring is one of the most primal precision medicines of all, because it primarily calls you and nobody else," says Manuela Filippa, a researcher at the Universities of Valle d'Aosta and Geneva. Scientists theorize that exposure to a mother's voice stimulates a newborn's brain to develop optimally to interpret sounds and understand language.

TWELVE YEARS AFTER Teresa McKeown beat stage 3 breast cancer with a brutal regimen of chemotherapy and a double mastectomy, the disease returned, more aggressively than before. This time chemotherapy failed. Day after day, she sat in a chair in her living room, too sick to move. She kept four journals, one each for her husband and her three grown children, and mustered the strength to write her thoughts about a future she didn't expect to share.

She withered to 98 pounds because tumors in her bowel made it almost impossible to eat. McKeown is not one to rage or panic, but before surgery to remove the blockage, she made a rare admission of anguish. "I am so praying that if things are not going to end well for me or there is a complication following this surgery, that I just pretty quickly pass away," she recalled telling her older daughter. "I don't know how much more pain I can tolerate."

Desperate and determined, she asked her surgeon, Jason Sicklick, if he knew of any experimental treatments that might buy her more time. As it happened, he is a co-leader of a study at the cutting edge of what's come to be called precision, or personalized, medicine.

The approach, built on advances in gene research and data analytics, holds transformative possibilities for cancer treatment and could upend the way medicine traditionally has been practiced. Rather than lump patients together under broad categories of diseases, precision medicine aims to tailor prevention, diagnosis, and treatment to a person's unique biochemical makeup.

McKeown joined I-PREDICT, a precision cancer study at the University of California, San Diego-affiliated Moores Cancer Center. Researchers there don't rely on any particular therapy. Instead they analyze the DNA in a patient's cancer cells. Using special algorithms, a computer then scours data on thousands of gene variants, hundreds of anticancer drugs, and millions of drug combinations to find the treatment that best targets the tumor's abnormalities. It may be a new immunotherapy, old-line chemotherapy, hormonal therapies, or drugs that aren't specifically approved for cancer.

"It's a very simple principle," said Razelle Kurzrock, an oncologist and director of the Moores Center for Personalized Cancer Therapy. "You pick the right drugs for each patient based on the tumor profile, not based on a part of the body or based on what type of cancer 100 other people have. It's all about that patient sitting in front of me."

McKeown's tumors were riddled with different mutations. "These are the kinds of patients we used to hang our heads and feel sorry for," Kurzrock said. But they're among the best candidates for a new class of immunotherapies called checkpoint inhibitors. The drugs prevent tumor-made proteins from binding to immune cells and shutting them down, which restores the patient's ability to fight the cancer. More mutations mean the reactivated immune cells have more targets to attack and eradicate.

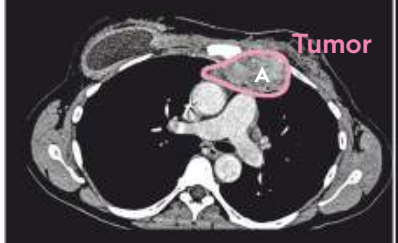
I-PREDICT matched McKeown with nivolumab, a checkpoint inhibitor approved for advanced melanoma, kidney cancer, and certain lung cancers but not for breast cancer. After two infusions, the tumor

CANCER KILLERS

Judy Perkins is surrounded by white blood cells known as tumor-infiltrating lymphocytes, or TILs, which cured her breast cancer (see the CT scans below). When Perkins was first diagnosed, she had her left breast removed, but the cancer returned. Despite chemotherapy, hormonal treatments, and targeted therapies, a new tumor grew in her chest. When the cancer spread, she was given months to live. But in an experimental treatment devised by Steven Rosenberg at the National Cancer Institute, Perkins was infused with 82 billion of her own TILs, which she calls her "army" (graphic on the following pages).

Cross sections (seen from below) show the treatment eliminated the tumor.

BEFORE TREATMENT

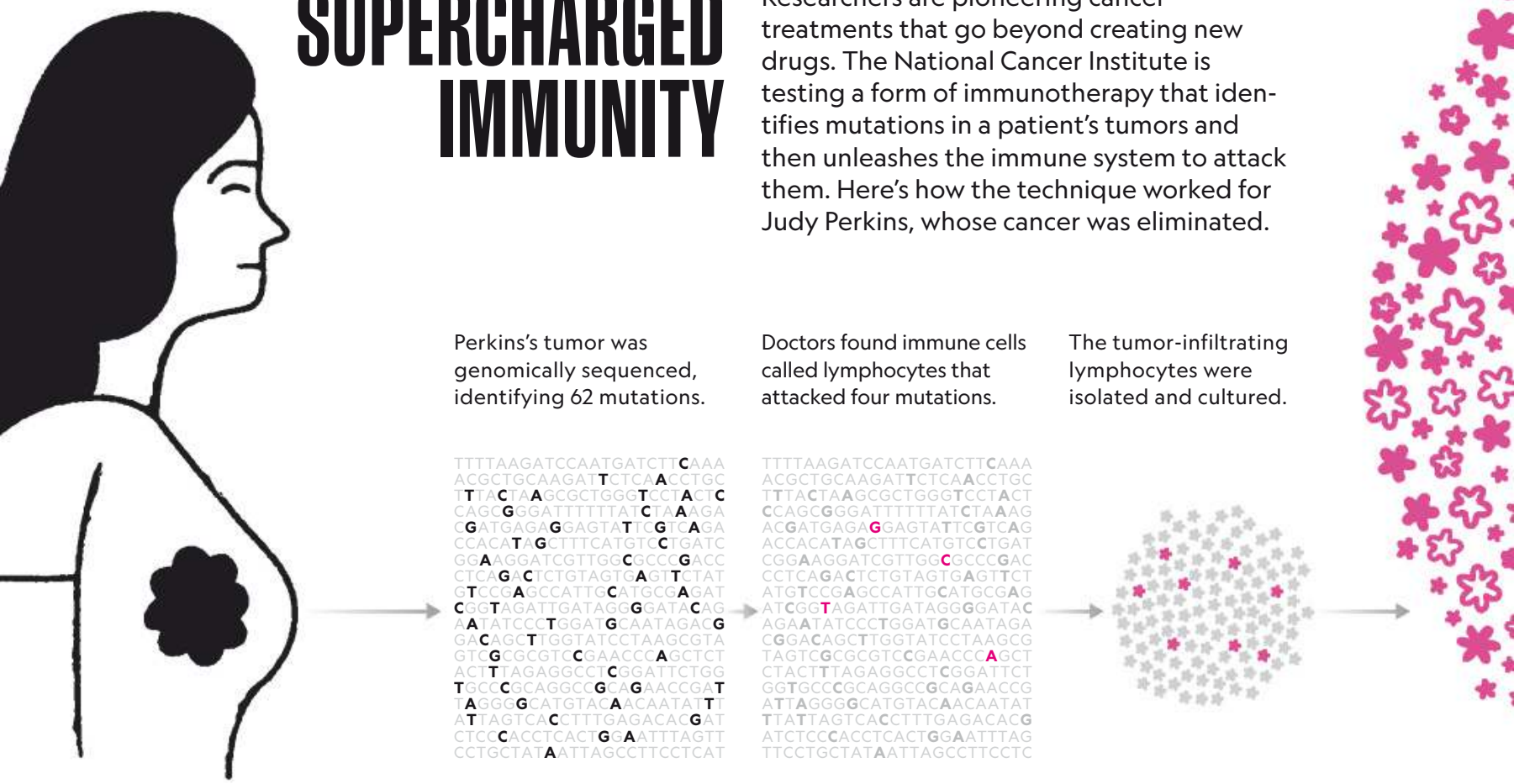


28 MONTHS AFTER

CT SCANS: STEVEN ROSENBERG, NATIONAL CANCER INSTITUTE

SUPERCHARGED IMMUNITY

Researchers are pioneering cancer treatments that go beyond creating new drugs. The National Cancer Institute is testing a form of immunotherapy that identifies mutations in a patient's tumors and then unleashes the immune system to attack them. Here's how the technique worked for Judy Perkins, whose cancer was eliminated.



markers in her blood declined by more than 75 percent. Four months later, after additional infusions, tests detected no evidence of cancer.

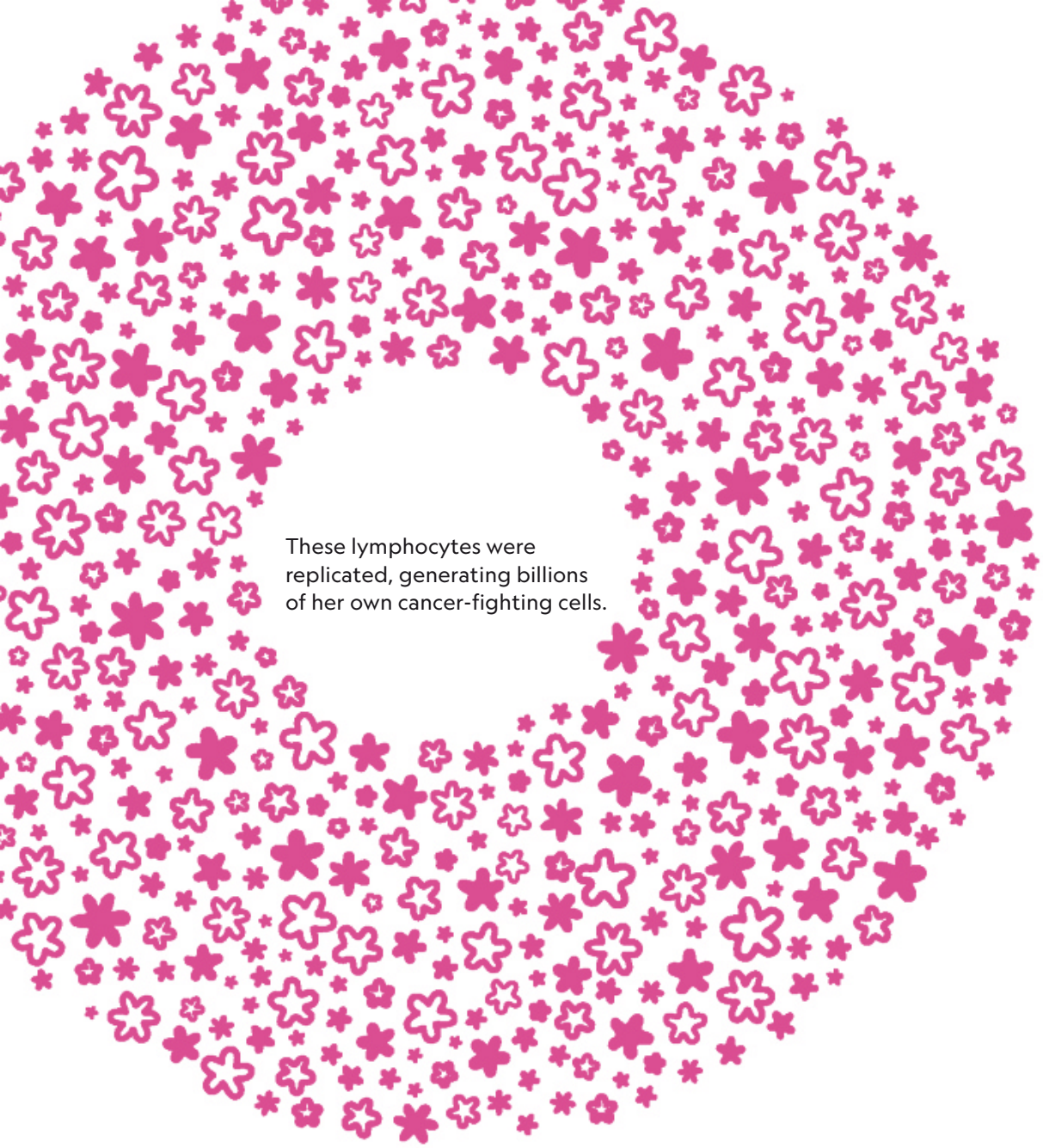
On a hot summer day, a year and a half after she entered the trial, McKeown, 57, showed me around her garden in Valley Center, California. It's a three-acre expanse of lawns, blooming trees, and rosebushes of red, white, lavender, orange, and brilliant yellow nestled, improbably, amid the parched, scrub-covered hills.

"I just feel so grateful," she said. "I love this whole notion of individualized medicine. I love that they're figuring out what's causing that mutation and how to target it, as opposed to chemo that's so disruptive across the board. Can we just get there faster?"

PRECISION MEDICINE flips the script on conventional medicine, which typically offers blanket recommendations and prescribes treatments designed to help more people than they harm but that might not work for you. The approach recognizes that we each possess distinct molecular characteristics, and they have an outsize impact on our health.

Around the world, researchers are creating precision tools unimaginable just a decade ago: superfast DNA sequencing, tissue engineering, cellular reprogramming, gene editing, and more. The science and technology soon will make it feasible to predict your risk of cancer, heart disease, and countless other ailments years before you get sick. The work also offers prospects—tantalizing or unnerving, depending on your point of view—for altering genes in embryos and eliminating inherited diseases.

More immediately, the research points the way to customized therapies for the most recalcitrant cancers. Last spring, researchers at the National Cancer Institute reported the dramatic recovery of a woman with metastatic breast cancer, Judy Perkins, after an experimental therapy using her own immune cells to attack her tumors. The team, led by Steven Rosenberg, an immunotherapy pioneer, had sequenced her tumor's DNA to analyze the mutations. The



team also extracted a sampling of immune cells called tumor-infiltrating lymphocytes and tested them to see which ones recognized her tumor's genetic defects. The scientists reproduced the winning lymphocytes by the billions and infused them into Perkins, along with a checkpoint inhibitor, pembrolizumab. More than two years later, Perkins, a retired engineer from Florida, shows no signs of cancer.

One success story, of course, doesn't make a medical revolution. Two other patients in Rosenberg's trial died. "I'm a little point of light," Perkins said. "We need a lot more points of light to get the data to be able to harness the immune system."

The game changer may not be this treatment but what it says about the power of precision medicine. The distinctive mutations that fuel a person's cancer may be its undoing.

Thirty years ago, scientists thought that it would be impossible to crack our genetic code and sequence the 3.2 billion pairs of compounds in our DNA. "It was like you were talking fairy tales," Kurzrock said. "The conventional wisdom was that it would never happen. Never! And then in 2003, never was over."

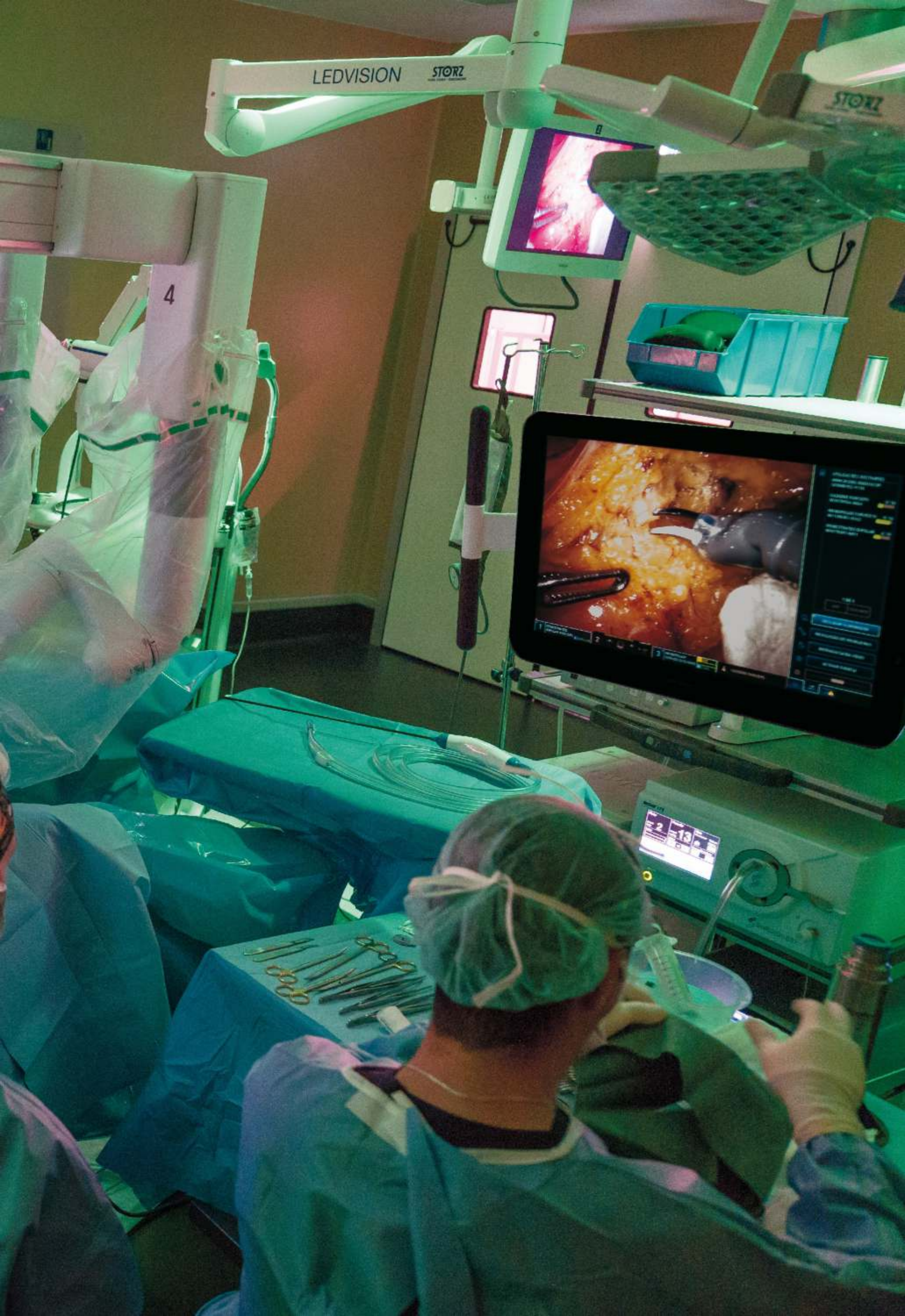
It took the Human Genome Project 13 years, roughly one billion dollars, and scientists from six countries to sequence one genome. Today sequencing costs about a thousand dollars. The latest machines can churn out the results in a day. The technology, combined with sophisticated molecular analysis, illuminates the astonishing biochemical variations that make every human body unique.

The more scientists discover about those differences, the cruder conventional medicine seems. Consider one-pill-fits-all prescribing. Most people who take a blockbuster drug, such as a statin or corticosteroid, benefit. But genomics reveals that many people don't. The Food and Drug Administration has identified about a hundred drugs that may not work as commonly prescribed in people with specific gene variants.

The problem can be deadly. The drug clopidogrel, for instance, is routinely given to prevent blood clots in patients after a heart attack. But about a quarter of the population has a gene

JASON TREAT, NGM STAFF; KELSEY NOWAKOWSKI
ART: CHRISTOPHER DELORENZO. SOURCE: STEVEN ROSENBERG, NATIONAL CANCER INSTITUTE

Surgeons remove a patient's malignant tumor at the Champalimaud Foundation in Lisbon, Portugal, with a da Vinci Xi robot's micro-instruments. Some of the cancer cells will be transplanted to zebrafish larvae and treated with the patient's chemotherapy regimen to test its effectiveness (shown on the following pages).


LEDVISION
STORZ
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Pu.1:Gal4 UAS:GFP
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M: Joana Monteiro
mpx:GFP
DOB: 31 – Aug – 2017
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Casper
O: Miguel Godinho
M: Telma Costa
mpx:GFP
DOB: 03 – Aug – 2017
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Nacre
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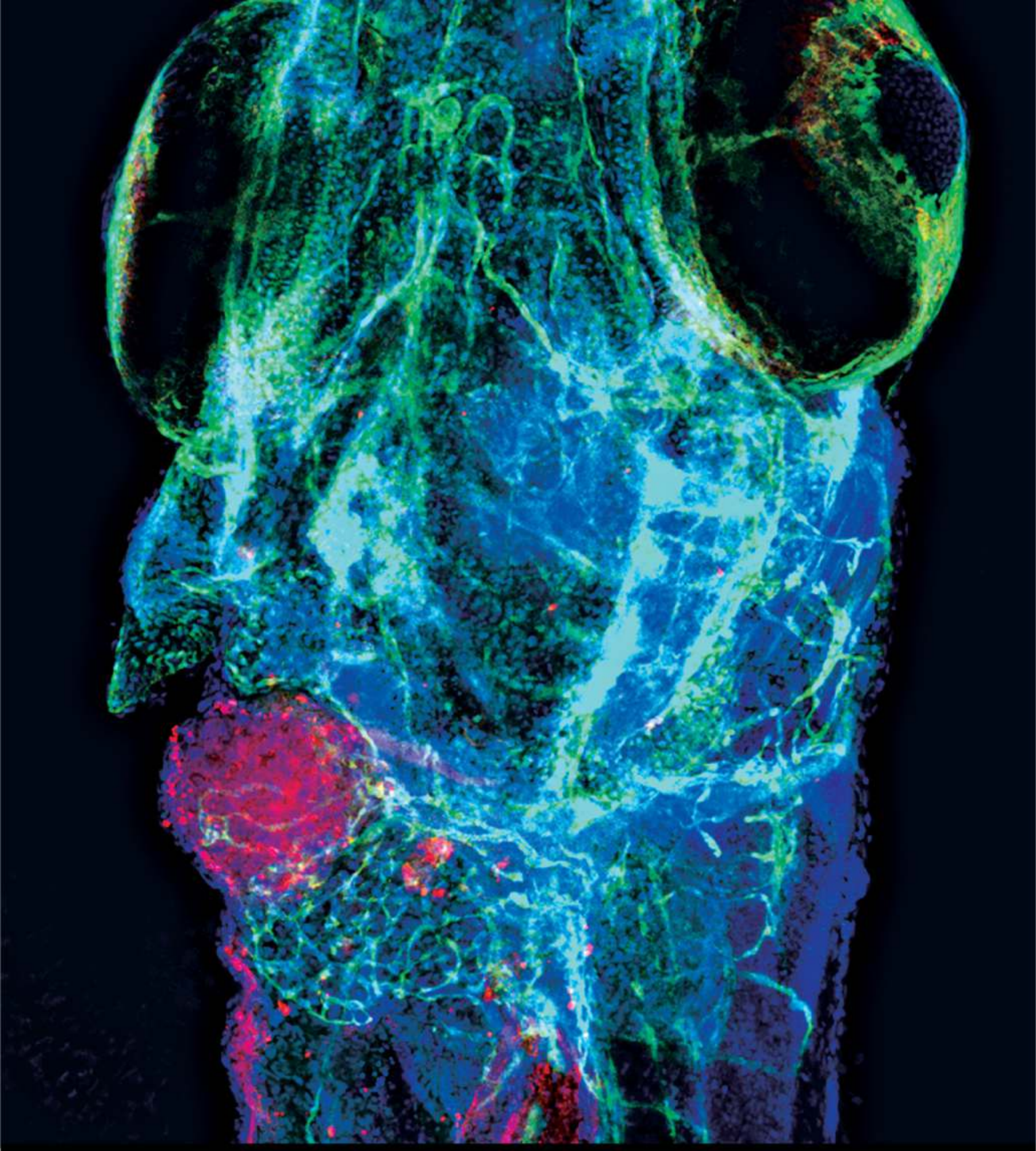


TUMOR-FIGHTING AVATARS

Zebrafish could become a powerful tool for identifying the best chemotherapy to kill a particular patient's cancer. Biologists Rita Fior and Miguel Godinho-Ferreira and their team at the Champalimaud Foundation injected tumor cells from patients into zebrafish larvae and tested them with the chemotherapy used on the patients. The larvae correctly predicted whether the drugs would work in four of the five patients. The scientists have expanded the study with more patients and other types of cancers. Mice bred with human tumors have been used for similar tests, but the procedure is expensive and takes months. Zebrafish can be easily and cheaply raised in tanks (left) and tested in just four days. In a zebrafish stand-in (above), human tumor cells appear magenta, while cell nuclei appear blue and blood vessels green.

ABOVE: RITA FIOR, CHAMPALIMAUD FOUNDATION

CONTINUOUSLY MONITORING THE HUMAN MACHINE

While precision medicine tailors treatment to one person, precision health uses detailed data to help people adapt their behavior and make healthy lifestyle choices. The goal: to avoid the need for treatment in the first place by passively collecting, transmitting, and storing health information as an individual goes about daily life.

While sleeping
Advances in electrodes small and flexible enough to fit in textiles could lead to pillowcases and sheets able to monitor brain waves and sleep patterns.

Upon waking
Toilets that check urine and stool for disease are being developed. In the future, smart mirrors could measure vital signs with radar, and toothbrushes might analyze saliva.

In the kitchen
Smart refrigerators might soon monitor the food stored and record its nutritional information. Food quality and freshness would be tracked, along with dietary habits.

Plugged in
Smartphones could analyze patterns that might indicate depression—such as a drop-off in social communication—and alert the user to address potential mental health issues.

variant that produces a defective form of an enzyme needed to activate the drug. Alan Shuldiner, a professor of medicine and a genetics researcher at the University of Maryland, found that when those people are prescribed the drug, they are twice as likely to have a repeat attack or die within a year of the first, compared with patients who don't have the variant. Some major medical centers now screen heart attack patients for the variant, but the test is far from routine.

Many experts say that a decade from now, a DNA profile will be part of everyone's medical record. Geisinger, a large health system in Pennsylvania and New Jersey, recently began offering genome sequencing as a routine part of preventive care, along with mammograms and colonoscopies.

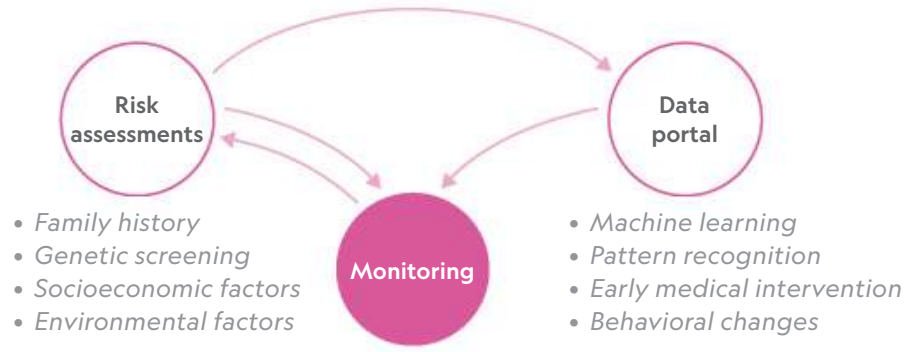
Like advances in computer chips, which liberated us from desks and then tethered us to smartphones, the shift to genomics and data-driven medicine will be disruptive in unpredictable—and perhaps distressing—ways. We soon will have at our fingertips extensive data about diseases we may develop over the course of our lifetimes.

TO GLIMPSE what that future might look like, meet geneticist Michael Snyder. He directs Stanford University's Center for Genomics and Personalized Medicine, and for the past nine years he has been tracking molecular and physiological markers in his body. The result is a high-definition depiction of his inner workings that registers fluctuations that may signal problems. It's like a weather map, charting shifts in the atmosphere to predict storms.

Snyder and the team in his lab take his DNA sequence into account as they analyze a continuous data stream. It includes measurements from blood, urine, and stool specimens he routinely provides and readings from bio-sensors he wears on both wrists, his ring finger, and his right arm. His team tracks his gene expression, proteins and metabolites, and physiological measures such as his exercise activity, heart rate, skin temperature, and blood oxygen. He undergoes MRIs, echocardiograms, and other scans to detect changes in his organs, muscles, and bone density.

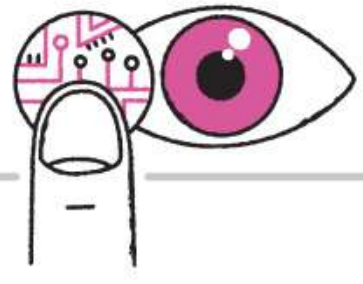
Snyder is not a hypochondriac. At 63, he's lean, and if not for his receding hairline, he

A positive feedback loop
An individual's health risk factors are assessed, then compared with large-scale population data, which can suggest beneficial choices or interventions. Passive monitoring throughout the day is key to constantly improving outcomes.



In the car
Sensors could warn a driver about dangerous pollution levels, high blood alcohol content detected on the breath, and driving that indicates stress and drowsiness.

On the run
Electronics like Fitbits or electric membranes attached to the skin can track exercise, vital signs, and ultraviolet exposure, while a "smart bra" might detect breast cancer.



In your body
Contact lenses may soon check pressure and glucose levels in the eye. Implantable technologies already monitor cardiac activity, nitrogen, and oxygen levels.

In the lab
"Electronic noses" could detect volatile organic compounds in the breath or in secretions such as sweat and saliva to find "smellprints" of diseases, including lung and ovarian cancer.

could be mistaken for a postdoc half his age. He has devised ways to perform genetic and molecular analyses, starting a dozen biotech companies. At Stanford, he's trying to apply this work to detecting illness at its earliest stages, before it causes problems. He became his own guinea pig because he didn't think anyone else would stick with all the tests and monitoring.

"Who knew I would turn out to be so interesting!" he said.

Four years ago, his sensors picked up an infection, through changes in his heart rate and blood oxygen level, before he felt sick. When he developed a fever, he suspected Lyme disease. By the time the standard test confirmed his hunch, he had already finished a course of antibiotics.

He also watched himself develop type 2 diabetes. His DNA had shown a predisposition, but he'd dismissed it because he was slim and had no family history of the disease. After a nasty viral infection, his glucose level shot up and stayed high, so he thought he might have diabetes. His doctor initially brushed off the possibility, as he had, but tests confirmed the disease.

He gave up sweets, doubled his bicycling, and started running four miles four times a week. He tracked the foods that spiked his glucose—"barbecued pork," he moaned sorrowfully—and adjusted accordingly. Over nine months his glucose returned to normal. Meanwhile he has recruited more than a hundred volunteers for similar profiling.

I signed up and went to Stanford for a battery of tests, including genome sequencing. Orit Dagan-Rosenfeld, a genetic counselor and researcher in Snyder's lab, ushered me into a small office, and then she walked me through the consent forms.

Did I understand that DNA sequencing might yield "actionable" results, such as *BRCA* mutations for breast and ovarian cancer, the problem that had famously spurred Angelina Jolie to undergo a preventive double mastectomy? Did I understand the test also might reveal problems I can't do anything about, such as the *APOE4* gene, which elevates the risk of Alzheimer's? Did I want to learn all findings, only actionable ones, or none and simply donate the data to research?

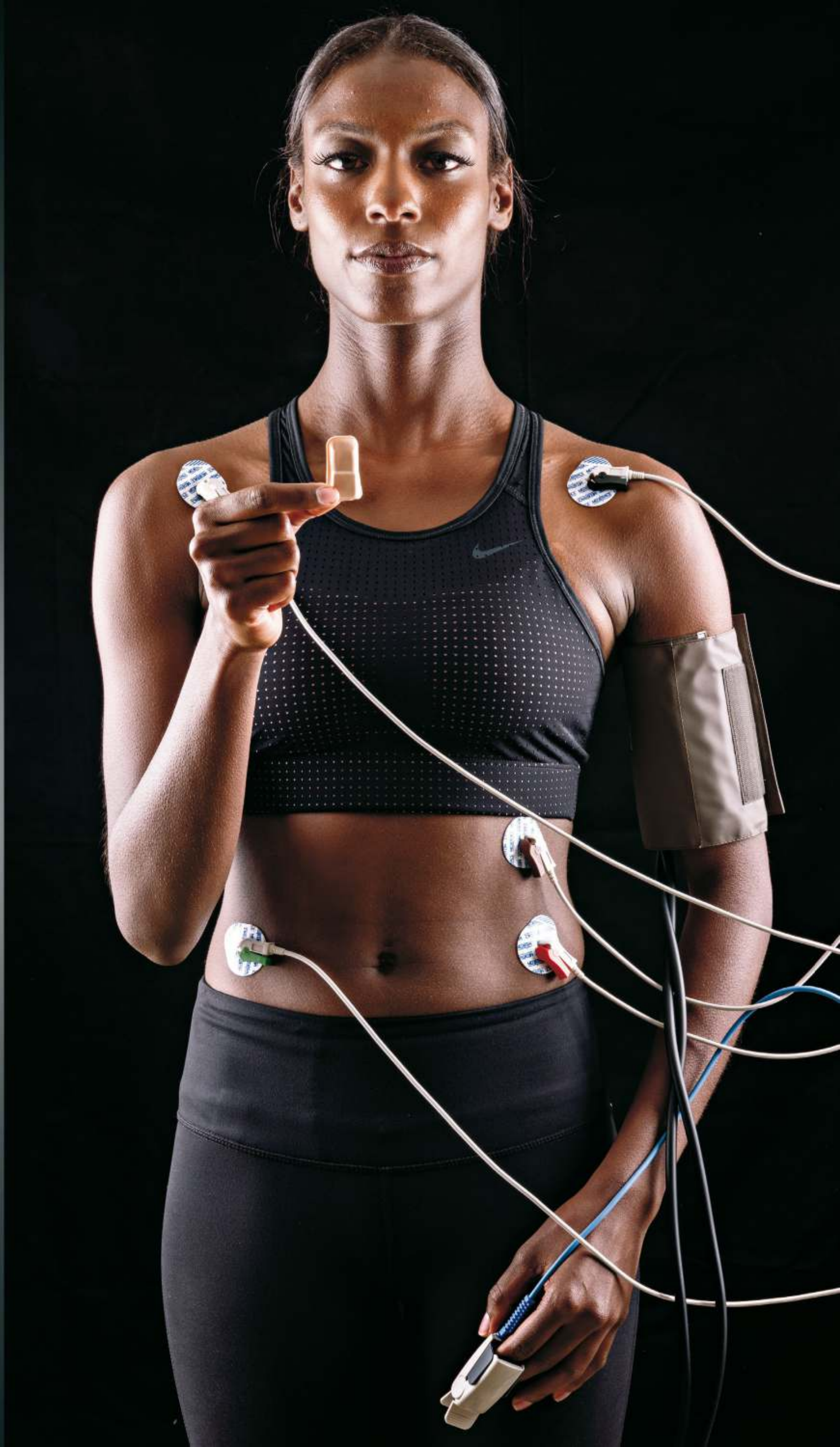
JASON TREAT, NGM STAFF; KELSEY NOWAKOWSKI
ART: CHRISTOPHER DELORENZO. SOURCE: SANJIV SAM GAMBHIR, STANFORD UNIVERSITY

WEARABLE SENSORS

Through dramatic advances in technology, miniature wireless devices are replacing bulky monitoring machines to track patient vital signs. The innovation will allow more extensive monitoring and earlier intervention, potentially saving lives—and billions of dollars. Engineers at Northwestern University have invented a number of stick-on devices (shown at right without their covers). The soft sensor the model (far right) holds in her right hand adheres to the skin and performs all the functions of a standard hospital monitor—and does even more.

1. Pulse oximeter for preemies, to measure blood oxygen level.
2. Sensor worn on fingernail to track ultraviolet exposure.
3. Sensor to detect UV and blue light from screens and LEDs.
4. Electrocardiograph (ECG) to measure electrical activity of a newborn's heart.
5. Battery-free UV dosimeter for melanoma patients.
6. ECG and seismocardiograph, which operates as a digital stethoscope.
7. ECG and heart-sound sensor.

SOURCE: JOHN A. ROGERS RESEARCH GROUP AT THE SIMPSON AND QUERREY CENTER FOR BIO-INTEGRATED ELECTRONICS AT NORTHWESTERN UNIVERSITY



FROM DNA TO BIG DATA

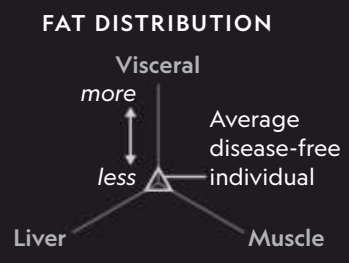
In freezer trays cooled to -112°F, the UK Biobank stores blood, urine, and saliva samples from more than 500,000 people. A robot retrieves specimens that scientists use to find links between genetic variants and disease. MRIs performed on some participants create 3D images (above) that show subcutaneous fat under the skin in blue and visceral fat around the organs in red. Visceral fat has been linked to diseases (following page).

AMRA MEDICAL AB (MRI)


UNIT 144

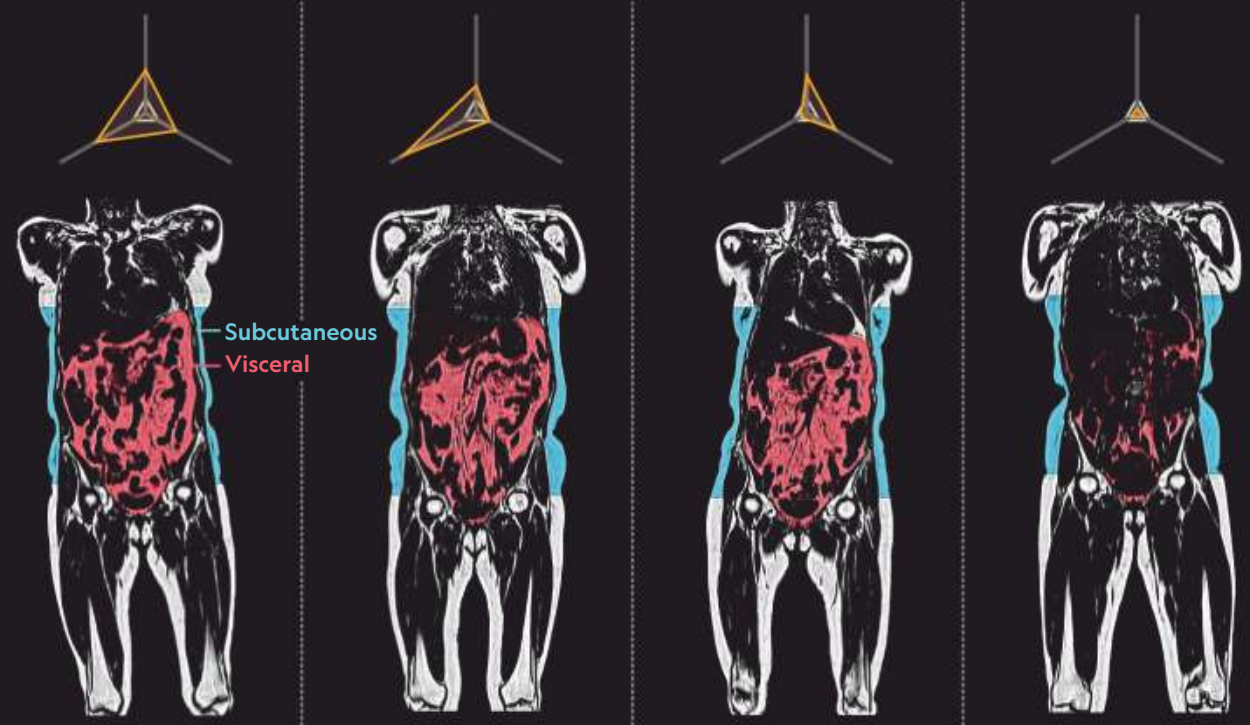
IT'S NOT THE FAT– IT'S WHERE IT'S AT

Body mass index (BMI) has long been used to measure obesity and health risk, yet it can't explain why an overweight person might be healthy or why a seemingly healthy person might get heart disease or diabetes. New MRI data show that when it comes to fat, where it's located matters most.



Subcutaneous fat, under the skin, can be less harmful than visceral fat, found around the organs. Visceral, liver, and muscle fat (orange lines, below) are linked to metabolic diseases.

Normal weight
Four women with a BMI of 24 but different fat distribution



Probability of:	*Less healthy*			*More healthy*
Heart disease	▲ High	▼ Low	▲	▼
Type 2 diabetes	▲	▲	▼	▼
Metabolic disease	▲	▲	▲	▼

Less healthy ← → *More healthy*

Obese
Four women with a BMI of 32 but different fat distribution

KURT MUTCHLER AND JASON TREAT, NGM STAFF; KELSEY NOWAKOWSKI
SOURCES: UK BIOBANK; JENNIFER LINGE, AMRA MEDICAL AB

I checked the boxes to tell me all. My stomach surprised me by knotting in protest. Nurses swabbed the inside of my nose and cheeks and drew 16 vials of blood.

At odd moments while I waited for the results, my mind replayed my father's 10-year descent into dementia. Was that my genetic legacy? To stop brooding, I'd turn my mind to my mother. At 94, she lives on her own in New York City, gets around by bus and subway, and dances and plays mah-jongg at senior centers. The promise of genome testing is to give people more control over their health. But for the first time I came to think of mine as an inheritance—maybe a lucky one, or not, but disconcertingly beyond my command.

The DNA test found nothing bad, Dagan-Rosenfeld said right off the bat when we went over the results by video. I was grateful. But I didn't feel as relieved as I'd expected. By then I'd learned how far science has to go before it understands what DNA can tell us.

I did learn that I metabolize some drugs poorly, including clopidogrel, so I should ask for alternatives if a doctor recommends them.

Snyder has turned up important genetic findings in about 17 percent of his volunteers. One had been on medication for type 2 diabetes for years—wrongly, it turns out, because he has a rare, inherited form of the illness. Another has a mutation for cardiomyopathy, a disease of the heart muscle that often goes undetected until it causes death.

For five years Snyder managed to keep his diabetes in check. Then his blood sugar crept up. Although he tried different diets and lifting weights, it continued climbing. He started taking medication. After a few months it didn't appear to be working either. He thinks his lifestyle adjustments forestalled the problem. But his saga holds a cautionary note. Even the latest precision medical technology—and a near-religious devotion to maintaining health—may not override vulnerabilities embedded in DNA.

GENOMICALLY SPEAKING, we're more than 99 percent alike—but separated, on average, by millions of genetic variations. At last count, scientists had cataloged 665 million, ranging from big alterations to differences in one of the nucleotides that make up DNA.

Which variants are harmless quirks, and which pose dangers? Like parents staring at tiny toy parts and baffling assembly instructions, scientists have barely begun to figure it out.

The challenge is illustrated by an experiment conducted at Vanderbilt University. Investigators studied 2,022 people and identified 122 rare variants in two genes known to be associated with heart-rhythm abnormalities. They asked three labs to determine which variants cause the irregularities. One lab selected 16; another, 24, and the third, 17. The labs all agreed on only four. The researchers then compared the lab assessments with people's health records and found that almost no one with potentially worrisome variants had abnormal heart rhythms.

To understand what the DNA code is saying requires huge studies over years, because risky mutations are rare and their related illnesses may take a long time to develop. The National Institutes of Health recently kicked off All of Us, part of its Precision Medicine Initiative, to collect DNA and other health information from a million people. The Dubai Health Authority plans to create a genomic database of the emirate's three million residents.

Leading the pack on such megastudies is the UK Biobank. Tucked into an unremarkable industrial strip in Stockport, England, the biobank holds the medical secrets of 500,000 British volunteers, ages 40 to 69. A freezer, the width of a two-lane road and nearly two stories tall, stores samples of their blood, urine, and saliva—10 million specimens in tiny tubes, stacked in trays and stamped with bar codes to protect anonymity. A yellow robot trundles along a track, plucking specimens for studies. The air is compressed and dried so thoroughly to prevent frost that even standing outside the freezer, looking at it through a glass wall, my skin felt more like old leather than a living organ.

Biobank computers link to the health records of participants, because the clues in DNA reveal themselves only when researchers can tie gene variants to traits and ailments in people. "Everybody unfortunately will be informative in the long term," said Rory Collins, the biobank's chief executive and principal investigator. "But only a small portion of people will be informative about a particular disease." The biobank has genotyped tissue from every donor. The process, commonly used by consumer DNA test companies, scans the genome for specific variants. The

CONCEPTION'S PERFECT TIMING

After in vitro fertilization, Carolyn Bilson holds up her ultrasound marked "G.L." for good luck by Ilan Tur-Kaspa (in blue), the medical director of the Institute for Human Reproduction in Chicago. Bilson and her partner, Tim O'Brien, conceived Westley (right) with personalized embryo transfer. Tur-Kaspa sampled 238 genes from Bilson's uterus to determine when she would be most receptive to implantation. An interim study found a 24 percent rise in IVF pregnancy rates with this method. The ultrasound image of Bilson's uterus (top left) shows her endometrial lining is 8.9 millimeters thick, usually enough for implantation. But the genetic testing found that the optimum window would be two days later, and she would need more hormonal treatments. Another ultrasound image (top right) shows Bilson's son sucking his thumb 13 weeks after conception.

ABOVE: COURTESY BILSON/O'BRIEN FAMILY (ALL)

biobank is now working with a pharmaceutical consortium to sequence every donor's exome, the protein-coding portion of the genome. Genotyping can find oddities and defects that researchers know to hunt for; sequencing can unearth new ones.

More than 4,000 researchers around the world are using the biobank's data trove to study the genetics of such conditions as cancer, osteoporosis, and schizophrenia and such habits as using marijuana and being a night owl.

The research, though, has limited applications to diverse populations because it tracks a largely white group. Other big genetic databases have the same drawback. A 2009 analysis of studies examining the links between genes and disease found that 96 percent of the participants were of European descent. Seven years later, University of Washington investigators reported some improvement, mostly because more studies were being done in Asia. Stanford researchers have warned that unless scientists study humanity in all its diversity, genomic advances will benefit only "a privileged few."

Nevertheless, researchers are using the data to push the bounds of personalized medicine. Scientists at the Broad Institute in Cambridge, Massachusetts, recently unveiled a personal risk scorecard of sorts—algorithms that calculate the odds you'll develop five serious, common ailments: heart disease, breast cancer, type 2 diabetes, inflammatory bowel disease, and atrial fibrillation.

The scorecard builds on an unsettling discovery: Many people have numerous mutations that each pose negligible risk but cumulatively present a problem. For instance, in breast cancer these little mutations collectively are as dangerous as a *BRCA1* mutation and far more common, said Sekar Kathiresan, who led the research. Many people harbor these bundles of defects and don't know it. In the not too distant future, Kathiresan said, doctors will use systems like this to score people's risks, perhaps even at birth.

At last count, scientists had cataloged 665 million gene variants. Which are harmless quirks, and which pose dangers?

ONE AFTERNOON last spring I sat down at a monitor at the Cedars-Sinai Board of Governors Regenerative Medicine Institute in Los Angeles to see a magnified view of cells under the microscope. A few months earlier, these blobs were blood cells collected from an adult donor. Scientists engineered them into primitive stem cells. And then a team led by Clive Svendsen, a neurochemist and the institute's director, turned them into a rudimentary version of the spine—nerve tissue bearing the donor's genetic signature. "Seems like science fiction, right?" he said. "Not long ago, it was science fiction."

The point of this cellular shape-shifting is to create models for studying disease. Not some generalized system, but a working model of a specific patient's specific disease. So an ovarian cancer researcher in Svendsen's lab wants to synthesize mini-versions of fallopian tubes from the blood of an ovarian cancer patient. The gut team will make intestinal tissue from the blood or skin of children with Crohn's disease. Svendsen studies Parkinson's and other neurodegenerative conditions, so his team produces brain and spinal tissue.

The scientists can start with almost any adult tissue. They reprogram it, using proteins involved in gene expression to turn back the clock and convert the mature cells to embryo-like ones. The reprogrammed cells, called induced pluripotent stem cells, are then placed into a brew of growth factors and other proteins. The recipe is crafted precisely to synthesize any functioning tissue a researcher wants.

Once they create it, the scientists pull the tissue apart and lay the cells onto a chip—a translucent plate about the size of a memory stick. Made by Boston-based Emulate, the chip is lined with tiny channels that carry blood and nutrients to the cells and help them mature.

Svendsen said the model will be valuable for testing new drugs and predicting how a patient will respond to a given treatment. Figuring out which drug works best is often a miserable

process, he said, citing epilepsy as an example: "We put kids through three months of hell, trying one drug after another. With the chip, you can just put a different drug on every day until you find the one that shuts down the seizure."

Some critics believe reprogrammed cells on a chip offer only a limited view of what's happening in the body. I asked Svendsen how he'd know, for instance, if an epilepsy drug was toxic to the liver or heart. Simple, he said. His lab would use stem cells to create mini-versions of those organs and then test them with the medication.

JUST HOW FAR can cell and gene technologies push the limits of medicine? Shoukhrat Mitalipov's laboratory at Oregon Health & Science University in Portland hints at where we might be headed. Mitalipov, a native of Kazakhstan with a boyish crop of black hair and a wrestler's build, used the gene-editing tool Crispr-Cas9 to alter the DNA of human embryos.

Mitalipov and his international team cut a segment in the paternal gene to remove a mutation associated with the potentially fatal heart condition hypertrophic cardiomyopathy. They made the Crispr cut as they fertilized eggs from healthy donors with sperm from a man who has the disease. If these embryos could grow into babies, they wouldn't have the disease or pass the genetic defect down the family line. Mitalipov, director of the university's Center for Embryonic Cell and Gene Therapy, had no intention of carrying the experiment that far. The scientists grew the embryos for about three days, then removed the cells for further analysis.

Tinkering with embryo genomes and changing the gene pool of future generations was long considered taboo, but in 2015, researchers in China reported using Crispr on nonviable human embryos to modify the gene for beta-thalassemia, a potentially deadly blood disorder. Cutting the gene introduced more damage than it fixed. Mitalipov discovered no such problem. His repair technique didn't work in every case, but he believes that with more refinement it could be used to eliminate any of the 10,000 diseases associated with single mutations.

Whether or not his method bears out, the scientific community is coming to accept the inevitability of embryo modification. A 2017 report from the National Academy of Sciences and the National Academy of Medicine concluded that a clinical trial might be permitted, though only after more research and only in dire medical cases. The technology to do it is developing fast, and perhaps the impulse to stretch the bounds of possibility is coded in our genes.

As Mitalipov led me through a small room where his team experiments on embryo genes, I asked whether he worries that the work could lead to editing embryos for traits that parents prize. He flicked his hand in exasperation. "I don't do gene editing. I don't do manipulation," he said. "I do correction. Is that wrong?"

In 1978 the first "test-tube" baby, Louise Brown, also triggered anxiety about designer babies. Since then more than eight million babies have been born through in vitro fertilization and other reproductive technologies. The first heart transplant, in 1967, sparked fears that doctors would prematurely end the lives of comatose patients to harvest their organs. Now thousands of desperately ill patients around the world undergo heart transplants every year.

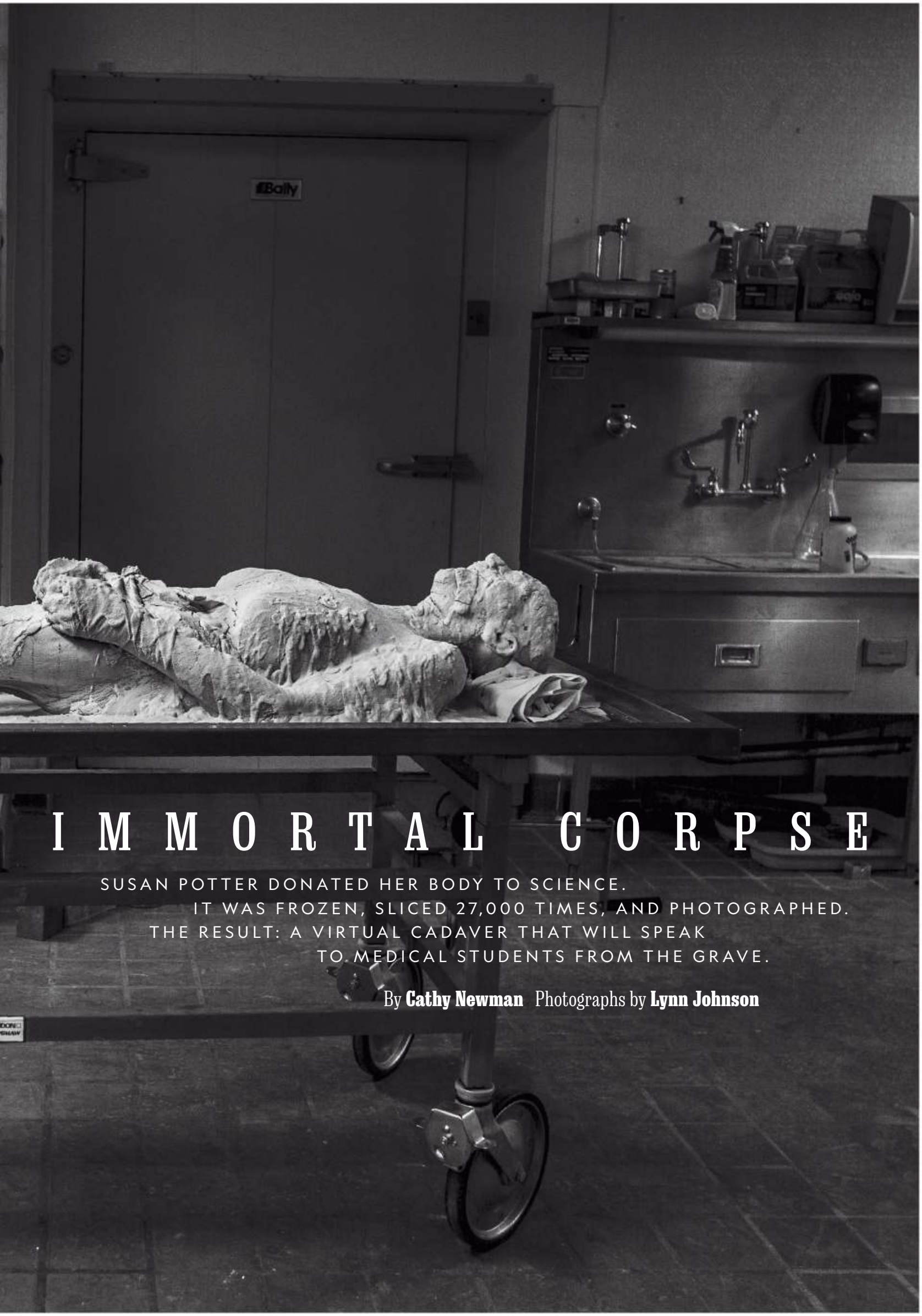
Even the simple home pregnancy test, available on any pharmacy shelf, set off an outcry when the FDA approved the first one in 1976. Some doctors insisted women would get too emotional about the results. A medical technologist, writing in the *American Journal of Public Health,* called for legislation "to limit the use of such potentially dangerous kits."

The fears faded as these breakthroughs became commonplace. The same thing may happen as DNA sequencing, gene editing, and other once unimaginable technologies become indispensable and progress saves lives. But the precision medicine revolution is unlike any other we've seen. It allows us to know what has always been unknowable about our bodies and to peer into our medical future. It moves science into a new realm of biological manipulation—and repair.

Judy Perkins, who is alive today because of advances in immunotherapy and gene technologies, believes the world should be clear-eyed about the power science has unleashed. "It's like nuclear energy," she said. "If it gets out of control, it can be really, really ugly. And if you harness it right, it's great." □

Fran Smith wrote the cover story on the science of addiction for the September 2017 magazine. **Craig Cutler**'s previous feature, in October 2014, was on biotechnology in agriculture.


THE



IMMORTAL CORPSE

SUSAN POTTER DONATED HER BODY TO SCIENCE.
IT WAS FROZEN, SLICED 27,000 TIMES, AND PHOTOGRAPHED.
THE RESULT: A VIRTUAL CADAVER THAT WILL SPEAK
TO MEDICAL STUDENTS FROM THE GRAVE.

By **Cathy Newman** Photographs by **Lynn Johnson**

Susan Potter demanded to visit 'the meat locker' before donating her body. She saw the room—and the machine that would grind her tissue away one paper-thin section at a time.

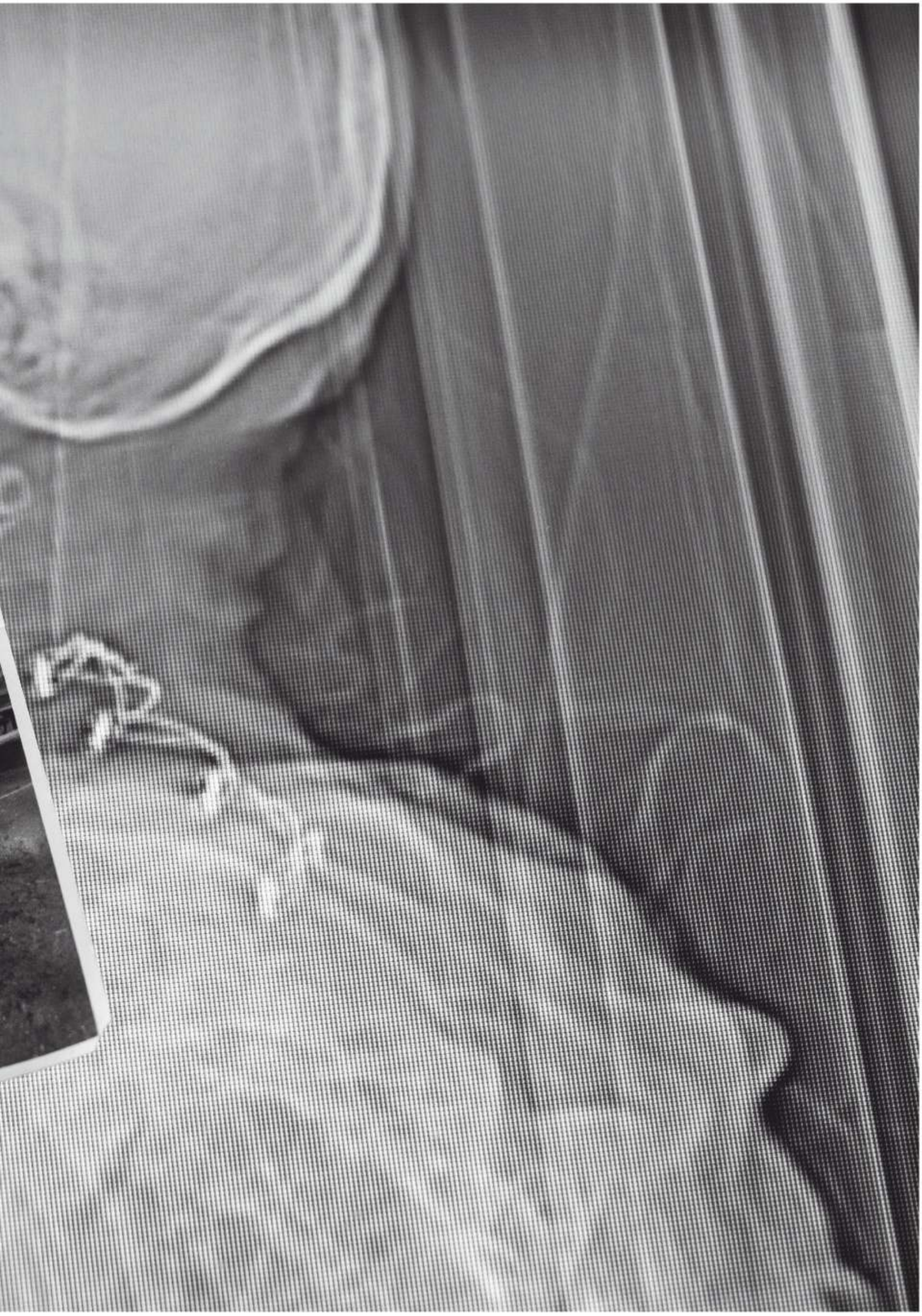
AUGUST 2005
Confined to a wheelchair because of an automobile accident, Susan Potter sped around, sometimes recklessly. "That's not my wheelchair—it's my Cadillac," she once snapped at a doctor. She lived alone in a modest apartment in a Denver suburb.

PREVIOUS PHOTO

MARCH 2015
In the first phase of her life after death, Potter lay encased in polyvinyl alcohol in a lab, the prelude to being frozen at -15°F, sectioned into 27,000 slices, then resurrected as a digital cadaver. She donated her body to the University of Colorado Anschutz Medical Campus to help students.


SABRE

Born in Leipzig, Germany, Potter was three in this photograph taken in her native country. Not long afterward, her parents immigrated to the United States, leaving her with relatives in a Germany traumatized by political instability, the rise of Hitler, and then World War II. The ghostly CT scan in the background was done upon her death at age 87. Wires had been used to stabilize her cervical spine after the car crash years before.



Susan Potter knew in exquisite and grisly detail what was going to happen to her body after death.

For the last 15 years of her life, Potter carried a card with these words: "It is my wish to have my body used for purposes similar to those used in the Visible Human Project, namely that photographic images might be used on the Internet for medical education…In the event of my death…page Dr. Victor M. Spitzer, Ph.D. …There is a 4-hour window for the remains to be received."

Potter knew because she visited the room where her body would be taken, saw the machinery that would grind her tissue away one paper-thin section at a time for imaging, and heard Spitzer, the director of the Center for Human Simulation at the University of Colorado Anschutz Medical Campus, explain the process more than a decade before she died. Spitzer didn't volunteer to show her the room; Potter demanded it.

I want to see the meat locker, she told him, meaning Room NG 004 in Fitzsimons, a former Army hospital on the grounds of the University of Colorado's School of Medicine, near Denver. "I will only donate my body after a tour from top to bottom."

JANUARY 2017
Vic Spitzer, director of the Center for Human Simulation, prepares to pry out a titanium rod from Potter's hip replacement. Left in place, it might have destroyed the cutting blade. Because she'd been frozen, the hip had to be thawed to remove the prosthesis.

"This story is about death," Vic Spitzer told me in March 2004, when I first met him to discuss his collaboration with Potter. "But in this case we're talking about the future dead." In fact, it's really a story about a relationship between two living people: a scientist with a vision to create a boundary-stretching, 21st-century version of *Gray's Anatomy* and a woman who volunteered for a project that would be realized only when she died. You could say that for the last 15 years of her life, Susan Potter lived for Vic Spitzer.

When Potter died of pneumonia at 5:15 a.m. on February 16, 2015, at the age of 87, her body was collected from the Denver Hospice, where she'd been admitted the week before. The cadaver, measuring five feet one inch from head to heel, 10 inches from back to front, and 19 inches from elbow to elbow, was placed in a freezer and frozen solid at minus 15 degrees F.

About two years later Spitzer and an assistant used a two-person crosscut saw to cut Potter's frozen corpse into four sections, a preliminary step in an ongoing process that will take years. Ultimately, Spitzer will resurrect and

APRIL 2003
The relationship between Spitzer and Potter was not without tenderness. She called him "the spook" and berated him for not phoning enough. "I think she would want me to visit her daily," he said with exasperation. Potter was committed to donating her body to his project, saying it would help medical students become compassionate doctors; Spitzer was committed to fulfilling her wish.


SOMATOM

It was a eureka moment. Suppose a virtual cadaver existed, one you could endlessly dissect, then restore to Lazarus-like intactness with a keystroke?

reconfigure Potter's body as a kind of digital avatar that can talk to medical students and help them understand how, in life, she was put together.

Anatomy is the bedrock of medicine. The body is what we present to our physician, says Robert Joy, professor emeritus of medical history at the Uniformed Services University of the Health Sciences. "The doctor asks, 'What is happening, and where is it happening?' To care for patients, the doctor must first learn the architecture of the body."

To learn the where, medical students spend their first year dissecting a cadaver. "The dead teach the living" is a tenet of medicine.

In part because of the taboo against desecrating bodies, human cadavers weren't used for education until the 14th century. Dissections were often done in public, but the students themselves didn't dissect. A senior faculty member sat in a chair and read from the works of the Italian physician Mondino de Luzzi. A junior academic pointed out the structures. A barber or surgeon did the cutting. It was Andreas Vesalius, a professor at the University of Padua, who brought students to the dissecting table in the 1500s.

"Dissection becomes part of medical school with Vesalius," says Mary Fissell, a professor in the Department of the History of Medicine at Johns Hopkins University. Greek physician Galen had dissected pigs, dogs, and apes. In the 1500s, Fissell explains, Vesalius pushed his own innovative-for-the-time point of view that human cadavers could best teach physicians human anatomy and, furthermore, that the student should do the dissection.

Dissection of a cadaver is like an archaeological excavation. To get to the deepest layers, one works from the top down. The process is anxiety provoking and enthralling—a medical school initiation rite with almost religious overtones.

"I remember the first time I held a heart in my hands," Donald Jenkins (who died in 2017), a former anatomist at the National Library of Medicine, in Bethesda, Maryland, told me, with tears in his eyes, speaking of the female cadaver he worked on. "This is the heart when she was married," he said. "I choke up when I think of it. It was profound."

Today students spend less time in the anatomy lab because so much new science—the field of molecular genetics, for example—clamors for their attention. In the early 20th century, according to the late David Whitlock, former chair of the University of Colorado's anatomy department, medical students spent a thousand hours studying anatomy. Now, says Wendy Macklin, chair of the Cell and Developmental Biology Department, it's no more than 150 hours. A cadaver is a costly, nonrenewable resource. Medical schools don't pay for cadavers but do pay for transportation, embalming, and storage. The 24 bodies used in the anatomy lab at the University of Colorado School of Medicine cost $1,900 each. (Every year about 180 people in Colorado donate their bodies for potential use in anatomy classes.)

ABOUT THIS STORY

"The Immortal Corpse" is a story that unfolded over 16 years. In 2002, Vic Spitzer, director of the Center for Human Simulation at the University of Colorado Anschutz Medical Campus, approached photo editor Kurt Mutchler to propose that the magazine follow his project: a woman body donor—still alive, then—who would be frozen and segmented after death to create a digitized cadaver for medical education. Photographer Lynn Johnson began her coverage the following year and decided to document Potter, while alive, in black and white. After death, her digital avatar would appear in color. Writer Cathy Newman joined the story team in 2004.

MICHAEL J. ACKERMAN, then the assistant director for high-performance computing and communications at the National Library of Medicine, had an epiphany. In 1987 he'd been speaking at the University of Washington about computer-based instruction in medical school. "After the lecture, the chairman of the anatomy department said, 'If you want to use computers for instruction, you should use it for anatomy,'" Ackerman recalled in his office when I interviewed him in 2005. Anatomical dissection is tricky, he was told.

If you do the dissection from the top, you can't see how the anatomical structures relate to each other from the opposite side.

It was Ackerman's eureka moment. Suppose a virtual cadaver existed, one you could endlessly dissect, then restore to Lazarus-like intactness with a keystroke?

That was the beginning of the National Library of Medicine's Visible Human Project. In 1991 a team headed by Vic Spitzer and David Whitlock at the University of Colorado was awarded a government contract grant of $720,000 for the acquisition of digital image "data representing a complete normal adult human male and female…from cryo-sectioning…cadavers." (The project, funded by the National Institutes of Health, eventually cost $1.4 million.) In short, Spitzer's team was asked to slice male and female cadavers millimeter thin and photograph each section, so the images could be assembled into a digitized compendium of human anatomy.

Spitzer, who is six feet four, walks slightly hunched on the balls of his feet, which are often clad in brown leather sandals even in the dead of winter. He's got a lean, angular face, a pronounced underbite, and a rapid-fire way of talking.

His specialty is anatomical imaging—the use of MRI and CT scans to figuratively turn the body inside out. His skill, shared with perhaps a handful of people in the world, is the full-body imaging of cadavers as a tool for medical education. Internal human geography is his passion. As a child, he was fascinated by the shoe-fitting x-ray fluoroscopes found in stores in the 1950s. He would slide his feet into the large wooden box of the apparatus and stare through the scope at the delicate arrangement of bones that enables humans to walk upright. His mother had to pull him away.

Years later, after studying physical chemistry at the University of Southern Colorado, he did graduate work in nuclear engineering and physical chemistry at the University of Illinois, where he met his wife, Ann Scherzinger, now also a professor at the University of Colorado Anschutz Medical Campus. Then he found his way to medical physics—a field that includes the science of body imaging. It was a perfect fit.

It took Spitzer two years to find a suitable male body to cut for the Visible Human Project. "We were looking for a normal body, less than six feet tall, with no trauma or previous surgery. The body had to be fresh. And what," he told me, "could be fresher than someone who is going to die on schedule? For this we needed a source. Which happened to be death row."

The cadaver was supposed to be anonymous, but when the press found out that the first Visible Human was an executed convict in Texas, it was easy to come up with the name of Joseph Paul Jernigan.

The 39-year-old convicted murderer died from lethal injection at 12:31 a.m. on August 5, 1993. Spitzer flew to Texas to collect the body, which was frozen, sectioned into nearly 2,000 millimeter-thick slices, and digitized. The images are on the National Library of Medicine's website, where anyone can file an application for the data.

The female, a 59-year-old from Maryland who had died of heart disease, was sectioned a year later. Spitzer's group, having proved the technique to the National Library of Medicine, cut her into more than 5,000 slices only 0.33 millimeter thick. As of this writing, 4,000-plus licenses for the Visible Human data have been issued for applications ranging from building better hip joints to creating virtual crash dummies.

One day in a lecture hall on campus, I watched Spitzer demonstrate a dissecting program he'd devised using the data. With the sweep of a mouse,

CLOCKWISE FROM TOP LEFT

AUGUST 2006
Ferociously independent, Potter did her own shopping. She proclaimed her patriotism with a bumper sticker on her wheelchair that declared, "God Bless America."

APRIL 2004
She thrived on opportunities to talk with medical students about her role as a prospective "visible human."

APRIL 2003
Potter had a physical with one of her many doctors to gather baseline information for her medical history. She'd undergone a double mastectomy for breast cancer.

AUGUST 2005
Spitzer occasionally visited Potter at her apartment, or they'd meet in the hospital cafeteria for lunch.

MAY 2009
Being a donor to Spitzer's project revitalized Potter. She "adopted" some University of Colorado medical students, met with them periodically, and here, attended their graduation. Several developed a strong attachment; others found her too demanding.

FEBRUARY 2015 Spitzer examines Potter's body resting in a freezer attached to his lab. Initially he rejected Potter's offer to donate her body—until he realized the value for students of having audio and video recordings of her before she died. The room stores other donated cadavers for use in advanced medical training and research.

he stripped the musculature to reveal the skeleton, then showed a cross section of an upper thigh that looked like nothing so much as a raw haunch of meat. He isolated the circulatory system, hovered over the heart, visualized it from a different angle, and reassembled the cadaver in its entirety.

Although Spitzer continued to develop medical education software and procedure simulators for his own company, Touch of Life Technologies, the NIH-funded Visible Human Project formally ended with Jernigan and the female counterpart.

Then Susan Potter entered his life.

BORN SUSAN CHRISTINA WITSCHEL on December 25, 1927, in Leipzig, Germany, she had immigrated to New York after World War II. In 1956 she married Harry Potter, an accountant for a golf course on Long Island, where they raised two daughters. When her husband retired, the couple moved to Denver.

She was thin, with a face like a raptor and watery blue eyes that narrowed when she was displeased. She spoke with

the inflection of her native Germany. Because injuries from an automobile accident made walking difficult, she used a motorized wheelchair—propelled as much by a get-out-of-my-way sense of urgency as by the chair battery.

By the time she met Spitzer, Potter, then 73, had been a presence around the grounds of the University of Colorado hospital for years. An activist for disability rights, she'd once rolled her wheelchair into a boardroom meeting chaired by the university chancellor, unannounced, waving a list of demands. ("If there is a stairway to heaven, it will be wheelchair accessible thanks to Susan," one of the speakers at her memorial service observed wryly.)

One day in 2000, Potter called Spitzer's office and got Jim Heath, his research assistant, on the phone.

"I'm Sue Potter," she said. "I read about the Visible Human in the newspaper, and I want to donate my body.

"I want to be cut up."

"She shocked me," Spitzer recalled. "She rolled in and started to talk about becoming a Visible Human."

Initially he wasn't interested. You don't fit, he told her. The Visible Human Project was about dissecting normal, healthy bodies. Potter's body had been deformed by decades of illness, including a double mastectomy, melanoma, spine surgery, diabetes, a hip replacement, and ulcers. "But I knew I was lying," Spitzer said. "I knew that one day we would need to start considering the diseased body," the type that doctors deal with routinely.

Spitzer envisioned an advanced version of the Visible Human Project. Are you interested in working with us before you die? he finally asked her. Are you interested in giving us more than just your body—in giving us your personality and knowledge?

Spitzer wanted to videotape her while she was living and record her talking about her life, her health, her medical history. Your pathology isn't that interesting to the project, Spitzer told Potter. But if I could capture you talking to medical students, when they're looking at slices of your body, you could tell them about your spine—why you didn't want the surgery, what kind of pain the surgery caused, and what kind of life you led after the surgery. That would be fascinating.

"They'll see her body while they're hearing her stories," he explained, adding that video and audio of her would make her more real and introduce the element of emotion to students. Instead of an anonymous cadaver, this "visible human" would be capable of delivering a medical narrative suffused with the recollection of frustration, pain, and disappointment. The images of Potter, like those of the Visible

Are you interested in working with us before you die? Spitzer finally asked her. Are you interested in giving us more than just your body—in giving us your personality and knowledge?


DRY ICE
HOW TO USE

CLOCKWISE FROM TOP LEFT

FEBRUARY 2015
In turning Potter's cadaver into a "visible human," Spitzer and research assistant Jim Heath (at right), apply a coat of polyvinyl alcohol to protect her skin from freezer burn and to provide contrast between the tissue and surrounding material.

JANUARY 2017
Lab manager Rachel Klaus (at left) and Spitzer remove the titanium rod from Potter's hip to prevent it from damaging the cutting blade.

MARCH 2017
The cadaver is measured and marked for fit. The sectioning machine can accommodate a block of anatomy 14 inches by 22 inches by 20 inches.

MARCH 2017
Spitzer labors with a two-person saw to cut the body into four blocks before sectioning it into hair-thin slices.


HOBART

Humans, would be on the internet, available anywhere, anytime.

Susan Potter had signed on to be an immortal corpse.

Dissecting a body is one thing. Teasing apart the tissue of human motivation, another. My first meeting with Potter, in 2004, took place at a nursing care facility where she was recovering from an infected leg suffered from a fall in her apartment in Aurora, the Denver suburb where she lived alone.

Photographer Lynn Johnson had been following her for several years, but Potter had steadfastly refused to see "the writer," as she called me. She relented when Spitzer explained that the magazine project would need the participation of someone to write the story.

APRIL 2018
This cross section is of Potter's head, encased in polyvinyl alcohol for stability. It shows her brain, eyes, and nose as the skull is sliced, from the top down, in the cryomacrotome, as Spitzer calls the milling machine. Potter's sectioning into 27,000 slices took 60 workdays to complete.

PREVIOUS PHOTO

MARCH 2017
The use of cadavers for teaching or research is predicated on the anonymity of the donor, but Spitzer had known Potter for 15 years. What were you thinking when you began to cut her? he was asked. "I was thinking that I was doing what she had asked me to," he said.

WHEN JOHNSON, Spitzer, and I walked into her room, she was sitting in an armchair. It was just before lunchtime, and Potter was about to initiate an inquisition.

"You don't call," she snapped at Spitzer before any of us had a chance to say anything.

"You're asking me to call you more than I call my mother," he replied.

She remained impassive. "Then you should call your mother more."

During the decade and a half that he dealt with Potter, Spitzer met with her more frequently in the beginning—usually for lunch in the hospital cafeteria. "The more you respond to her, the more she'll consume," he once said to me. "I think she would want me to visit her daily. She gets upset with me when I don't answer the phone or when I go out of town." He sounded exasperated but oddly tender.

She was like that with her doctors as well. She was always firing one doctor and acquiring another.

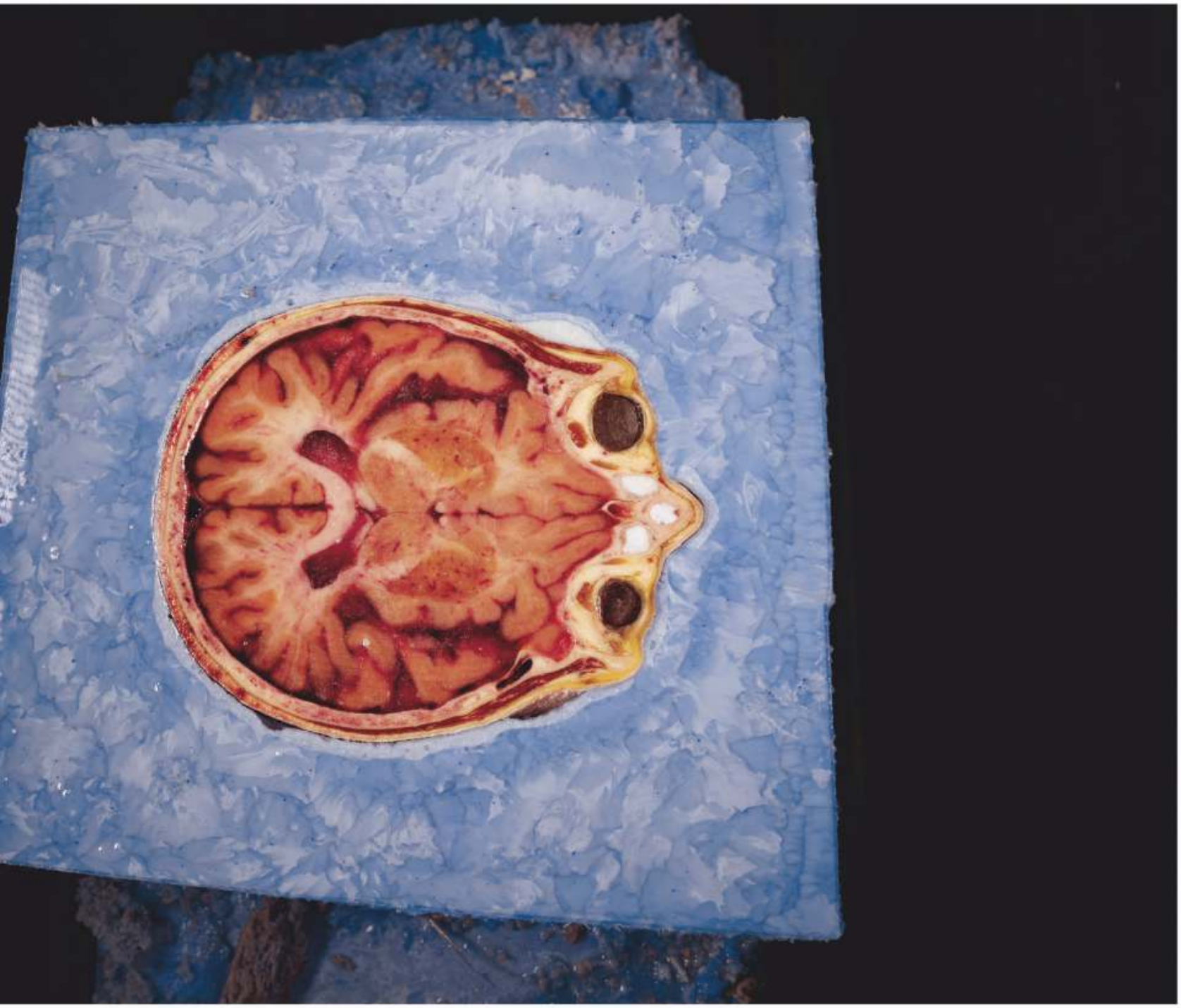
"How much time do you want a doctor to spend with you?" Spitzer once asked her, when she complained about a surgeon. "What if there's someone else dying?"

She's needy, isn't she? I said when he told me the story. "Yeah, sure," he replied. "Most of us are. Most of us want our hand held."

Spitzer made it clear that she could revoke her decision anytime.

"I never crossed the line and wanted her to die," he told me. "She knew what she was doing. I saw myself as conforming to her wishes. In all those years she never wavered."

If anyone wavered, it was Spitzer. He needed to stay convinced, he once told me, that the project would have a positive impact on health care education.



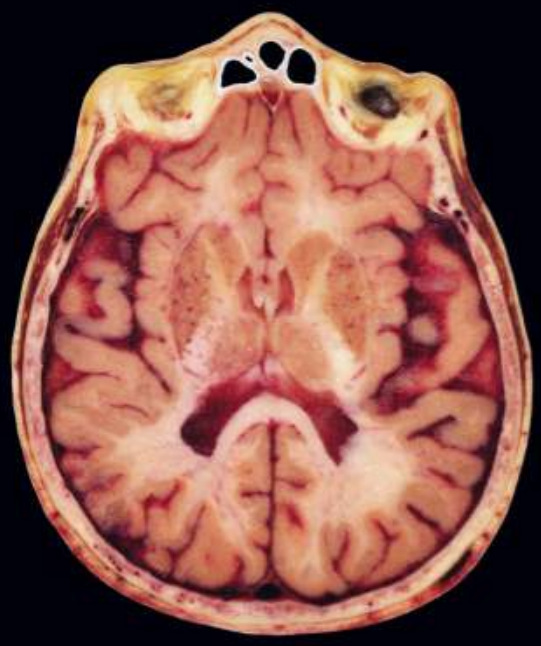
AS A RULE, a donated body remains anonymous. In the dissecting lab a donor list reveals age and cause of death, never a name. The head and face—the features most likely to provoke an emotional reaction—are dissected last and remain wrapped until the end. But Potter's donation was a public affair. She appeared at a Visible Human Project conference with Spitzer as well as in front of informal groups of medical students.

Once a staffer in her geriatric clinic accused her of seeking notoriety. "You just want your name on the wall," he told her.

Potter bristled. "If I can help young people become better doctors, that's my purpose," she retorted.

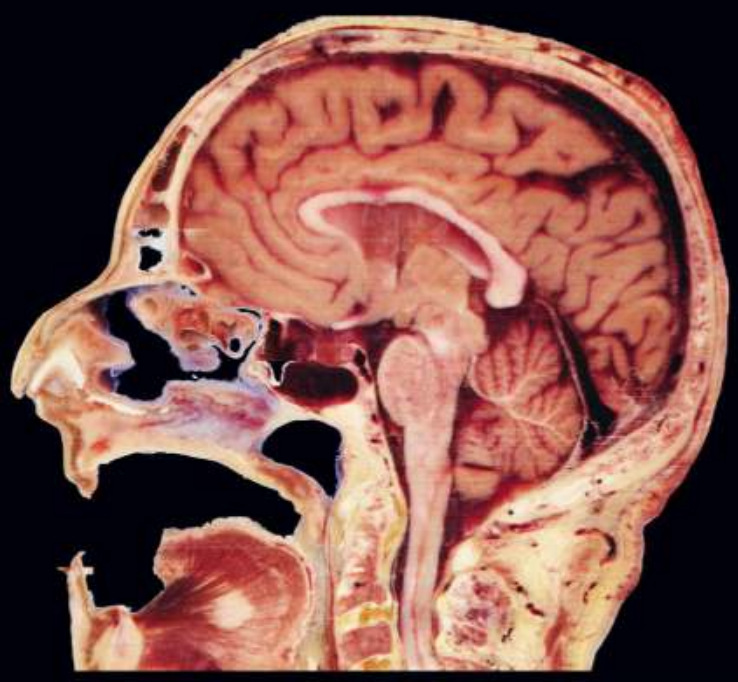
She was a woman of sharp edges, narcissistic, sometimes nasty, but also generous and caring. She knitted blankets and caps for premature babies in the hospital, volunteered at the hospital gift shop—until she was kicked out for carelessly running over a man's foot with her wheelchair—and "adopted" a group of first-year medical students (Team Susan, they called it) whom she'd invite to lunch, give presents to, and lecture on the need for compassion—something, she made clear, many of her doctors could use more of.

Transverse view

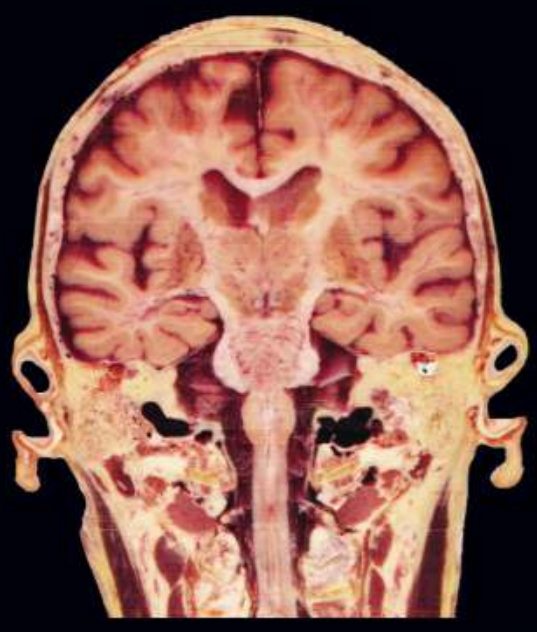


Instead of an anonymous cadaver, this 'visible human' would be capable of delivering a medical narrative suffused with the recollection of frustration, pain, and disappointment.

Sagittal view



Coronal view



FAR LEFT

Using software developed by Spitzer's group, Potter's skull can be rotated and seen from different angles. The entire skull can be visualized in more detail than current MRI and CT scans allow. Shown are views in three planes. From top: transverse (horizontal), sagittal (split vertically into left and right planes of the body), and coronal (split vertically from front to back of body).

LEFT

This layered, peeled-away cyber dissection of Potter's head and torso (photo, page 89) created from 6,900 separate digital images is an anatomical tour de force—impossible to achieve with a real cadaver. It can be manipulated in any number of ways that enable structures to be seen in relationship to each other. Arteries are highlighted in red, veins in blue, nerves in yellow, and the skeletal structure in white. Muscles and skin are shown in their true colors. Virtual cadavers are now widely used in medical education as an adjunct to actual dissection and, in some instances, as a replacement for the real thing. Human cadavers are limited in number and expensive to prepare. The cyber version is an endlessly renewable resource.

VIC SPITZER, JOHN MAGBY, AND RACHEL KLAUS, TOUCH OF LIFE TECHNOLOGIES (ALL)

When the visits from "her kids," as she called the students, diminished as they became overwhelmed by the demands of medical school, she badgered Norma Wagoner, the anatomy instructor who'd formed the group, to put together another.

"Of course I disappointed her by not jumping to do it again," Wagoner told me, "but she didn't understand how difficult it was for the kids. She has no idea other people have lives too. She sucks you in. Everything is a drama."

"What did you learn from Sue?" I asked Josina Romero O'Connell, one of Wagoner's most empathic students, years after she'd graduated from medical school and become a practicing physician.

She hesitated. "Patience," she finally said.

There was reason for the insatiable need for attention. Potter had endured a life of crushing abandonment. Her parents had left for the United States without her, leaving her as a young girl in Hitler's Germany with her grandparents, in a city that would be heavily bombed during World War II. When she was four, her beloved grandfather dropped dead from a massive heart attack. Ten years later her grandmother died. She ended up in an orphanage before going to stay with an aunt. When she finally arrived in New York after the war, neither parent—by then divorced—was at Idlewild airport to greet her.

She had survived a litany of loss and the war in Germany, but the emotional price was steep. "I have the skin of a hippopotamus," she once told me.

Tell me your favorite opera, I asked during one of my early visits, knowing she'd grown up in one of the most musical cities in Europe.

"Faust," she replied.

And who in your production would play the role of the devil?

"My mother," Potter said. "I've never been able to forgive that woman."

The younger of Potter's two daughters was in contact with her mother before she died, but neither attended the memorial service. Judging by the stories Potter told me, the relationship had been complicated and thorny, and she ordered me never to call them.

The bargain Potter made with the man who would cut her into 27,000 slices undoubtedly added meaning to her last years. In fact, it probably added years to her life. I was led to believe she was going to die within a year because of her multiple health problems. She lived for another decade.

Predictably, she tried to control the project after death too. She wanted classical music to be played during her "cutting" and the room to be filled with red roses. She wanted her teddy bear to be frozen and sliced with her.

Spitzer told her to forget that part.

"When are we going to see the pictures Lynn is taking?" she once asked me.

"You won't," I said, taking a deep breath. "They won't be published until you're dead."

She didn't blink.

THE COLLABORATION between the scientist and the donor reached its denouement on Friday, April 7, 2017. Spitzer had tried to get funding for his project, but the National Library of Medicine and potential corporate sponsors were not interested. He proceeded on his own, drawing on his company's funds and the help of graduate students in anatomy. Cutting Sue was a promise to be kept. And so, two years after her death, Spitzer and several students stood in

NG 004, the room where 17 years earlier Potter had taken a tour in anticipation of this moment.

Spitzer placed the torso, encased in a block of blue polyvinyl alcohol, on a stainless steel table in the chilled room. A carbide blade the size of a dinner plate began to grind off tissue in hair-thin, 63-micron increments.

After each pass of the blade, a digital camera photographed each exposed surface of the block. Imagine incrementally sanding a block of wood and photographing the layer of surface grain exposed each cycle. As with a block of wood, what's left of the corporeal Susan Potter is dust.

Spitzer had commissioned two students to paint red roses—not the fresh flowers Potter had requested, but close enough—over the door to the cutting room.

At 4:50 p.m., the blade, computerized and capable of running 24 hours a day, began to section her torso, and on a monitor in an adjoining room you could see the brown of liver, the gold of adrenal glands, and the marble of fat and muscle as cross sections of frozen tissue were ground down and photographed. In a bow to another of Potter's requests, a graduate student streamed classical music into a speaker system.

It was Mozart's *Requiem*.

Cutting the NIH-funded Visible Human Male into roughly 2,000 slices took Spitzer four months in 1993. Twenty-four years later, Susan Potter was cut into 27,000 slices in 60 days. Next comes the painstaking, time-consuming process of outlining the structures—tissue, organs, vessels—on each digital slice to highlight the skeleton, nerves, and vasculature in exquisite detail. That will take two or three years.

Now when Spitzer looks at Potter on the screen in digitized slices, he says, he sees her pain: the tortured, twisted arteries, the steel screws that stabilized her fractured cervical spine, an oddly misshapen kidney, and the arthritic joints that map the relentless decline into old age.

As for bringing Potter to life—having her interact with the viewer—that, Spitzer says, is a long-horizon endeavor. "I expect her to talk to you like Siri," he said, though he admits that piece of it will be for someone else to realize. Long after her death, Potter will still be a work in progress.

Spitzer often lectures on the Visible Human Project, and on my first visit to Denver back in 2004, I watched him talk to a group of high school students.

He explained the project and its applications—how the images are used in the anatomy lab as a reference while students dissect an actual cadaver, how simulators based on the data allow surgeons to practice their skills. On a virtual patient a scalpel slip is not fatal—it's just part of the learning process. He told his rapt student audience about Susan Potter and his vision of extending the Visible Human Project's scope.

"Ultimately we want a body to act like it's reacting to the outside world," he said.

"When will you stop?" a student asked, perhaps wondering just how far the science of digital resurrection could be pushed.

"Never," he replied, then added: "When the body gets up and walks away, then we'll be almost done." □

She wanted classical music to be played during her 'cutting' and the room filled with red roses. She wanted her teddy bear to be frozen and sliced with her.

Cathy Newman is a former editor at large whose most recent story, in the May 2017 issue, was about the Scottish moors. **Lynn Johnson,** a frequent contributor, is photographing an upcoming story about the autism spectrum.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For more than 2,200 years, Chinese healers have treated illness with a range of natural ingredients—including notoginseng, seahorses, rosebuds, licorice, and human placentas. These and thousands of other substances continue to be used every day in China and other parts of the world. (Go to *ngm.com/Jan2019* to learn more about the ingredients shown and what they're used for.)

In the fourth column, jars 4, 14, 24, and 34 hold ingredients being used in a promising cancer treatment developed at Yale, known as PHY906.

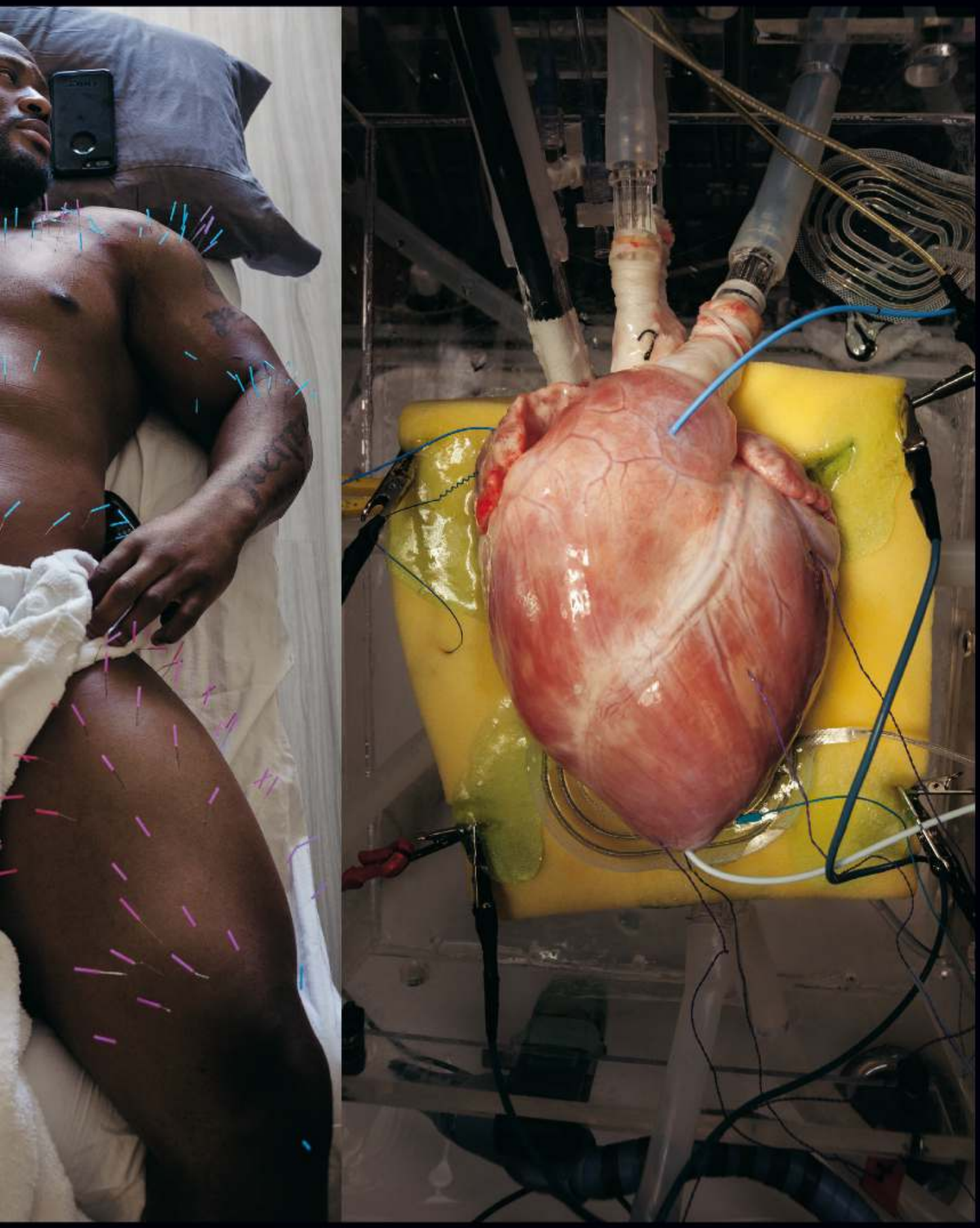
1. Safflower 2. Schizonepeta spike 3. Abalone shell 4. White peony root 5. Seahorse 6. Gastrodia tuber 7. Lotus leaf 8. Reed rhizome 9. Chinese angelica root 10. Chinese softshell turtle 11. Notoginseng 12. Rush pith 13. Hawthorn fruit 14. Baikal skullcap root 15. Citrus peel 16. Paper wasp nest 17. Molted cicada shell 18. Tuckahoe 19. Szechuan lovage root 20. Human placenta 21. Lophatherum stem and leaf 22. Cuttlefish bone 23. Citron daylily 24. Chinese date 25. Epimedium leaf 26. Night-blooming cereus 27. Frankincense 28. Trichosanthes fruit 29. Perilla leaf 30. Senna leaf 31. Asian white birch bark 32. Pangolin scale 33. Sweet wormwood 34. Licorice root 35. Rosebud 36. Chinese foxglove root 37. Monk fruit 38. Earthworm 39. Lotus seed 40. Cape jasmine fruit

ITEMS NOT TO SCALE. PHOTOGRAPHED AT EMPEROR'S COLLEGE OF TRADITIONAL ORIENTAL MEDICINE, SANTA MONICA, CALIFORNIA (2, 3, 6, 7, 8, 10, 12, 13, 16, 18, 19, 20, 21, 22, 27, 28, 33, 36, 40) AND NATIONAL WILDLIFE PROPERTY REPOSITORY, COMMERCE CITY, COLORADO (5, 32); SOURCES: ROBERT NEWMAN, EMPEROR'S COLLEGE OF TRADITIONAL ORIENTAL MEDICINE; AMY MATECKI, INTERNATIONAL CENTER FOR INTEGRATIVE MEDICINE

UNLOCKING THE EMPEROR'S MEDICINE CHEST

HOW ANCIENT CHINESE REMEDIES ARE CHANGING MODERN HEALTH CARE

By Peter Gwin • Photographs by Fritz Hoffmann



FAR LEFT

This 1620 version of *The Yellow Emperor's Classic of Internal Medicine,* first compiled some 2,100 years ago, includes a map of qi lines and acupuncture points. Acupuncture remains a contentious subject among Western doctors, though many agree it's effective at treating some symptoms.

PHOTOGRAPHED AT U.S. NATIONAL LIBRARY OF MEDICINE

CENTER

James Harrison relied on a form of acupuncture and other Chinese therapies to help him recover from pain and soreness during his 16-year NFL career. "If it makes me feel good," the recently retired player says, "I don't need no scientific proof."

LEFT

A pig heart at the University of Minnesota continues to beat hours after being infused with a synthetic version of bear-bile acid. For over a millennium, Chinese healers have prescribed bear bile for epilepsy, heart pain, and other ills.

In my hand I'm holding a warm, beating heart. About the size of a softball, it's a luminous globe of scarlet, pink, and white tissue.

I can feel its chambers contracting and hear the whoosh of the fluid it's still pumping. It's slimy and gives off a slightly pungent odor.

The organ is alive almost eight hours after I watched Paul Iaizzo remove it from a sedated pig in a basement lab, connect it to tubes simulating arteries and veins, and spark it back into rhythm with an electric jolt, as a paramedic would shock a human heart back to life. Although it's outside the pig's body, the heart flexes and lurches on its own, driven by some unseen, unexplained, primordial force. More than grotesque, I find it hypnotic and beautiful.

The pig's heart is still beating partly because Iaizzo, a professor of surgery at the University of Minnesota, treated it with a bath of chemicals mimicking those in bile from bears. It's a scientific application of a belief Chinese healers

Yale University professor Yung-Chi Cheng examines a notoginseng plant at a research center in China's Yunnan Province. Cheng is researching herbal treatments based on ancient Chinese formulas, including a cancer treatment that is currently in drug trials.

espoused as far back as the eighth century: Bear bile can benefit the human body.

A robust market for bear bile still exists. In Asia bears are farmed for their bile, kept alive in small cages, with catheters inserted to drain their fluids. Animal welfare groups decry the practice, which is inarguably inhumane. And yet, as I hold the beating pig heart and listen to Iaizzo describe how the chemicals that protect a bear's organs from atrophying during hibernation could also sustain human organs, I can't help but wonder whether bear bile could have saved my father's failing heart, or whether someday it might save mine, or my children's.

FEW SUBJECTS IGNITE more heated debate in health circles than traditional Chinese medicine. It's further complicated by the work of researchers like Iaizzo and many others who are looking at traditional cures through the lens of cutting-edge science and finding some interesting surprises—surprises that could have profound impacts on modern medicine. Cultures from the Arctic to the Amazon and Siberia to the South Pacific have developed their own medicine chests of traditional cures. But China, with one of the oldest continuous accumulations of documented medical observations, offers the biggest trove for scientists to sift through.

The Chinese record dates back to the third century B.C., when healers began analyzing the body, interpreting its functions, and describing its reactions to various treatments, including herbal remedies, massage, and acupuncture. For more than 2,200 years, generations of scholars added to and refined the knowledge. The result is a canon

Goji berries, said to improve sleep and athletic performance, among other benefits, dry at a farm in Qinghai Province. Demand for the berries is pushing production into new farming areas, such as Qinghai in northwest China, where the berries grow larger. The potency of the berries can vary due to differences in the soil and climate.

of literature dealing with every sort of health problem, including the common cold, venereal disease, paralysis, and epilepsy. This knowledge is contained in books and manuscripts bearing such enigmatic titles as *The Pulse Classic* (third century), *Prescriptions Worth a Thousand Pieces of Gold* (seventh century), and *Essential Secrets From Outside the Metropolis* (eighth century).

Traditional medicine remained the primary form of health care in China until the early 20th century, when the last Qing emperor was overthrown by Sun Yat-sen, a Western-trained doctor who promoted science-based medicine. Today Chinese physicians are trained and licensed according to state-of-the-art medical practices. Yet traditional medicine remains a vibrant part of the state health care system. Most Chinese hospitals have a ward devoted to ancient cures. Citing traditional medicine's potential to lower costs and yield innovative treatments, not to mention raise China's prestige, President Xi Jinping has made it a key part of the country's health policy. He has called the 21st century a new golden age for traditional medicine.

ALL THE CANCER PATIENTS WHO TOOK THE HERBAL FORMULA EXPERIENCED RELIEF FROM NAUSEA, BUT SOMETHING ELSE HAPPENED: THEIR TUMORS SHRANK FASTER.

From a research perspective, it very well may be a golden age. Scientists from leading universities in the United States and Europe, including UCLA, Duke, and Oxford, as well as many in Asia, are looking at the scientific underpinnings of some traditional treatments for diseases such as cancer, diabetes, and Parkinson's.

But the practice of melding the modern with the traditional is also spreading among health care consumers. When they don't find relief from Western medicine, Americans increasingly are turning to traditional treatments, notably acupuncture, which is now covered by some health insurance plans, and cupping, a muscle therapy that involves suction and is endorsed by many professional athletes. The internet has fostered the growth in herbal remedies, which are often cheaper than doctor-prescribed pharmaceuticals. A patient can read about a traditional remedy online, order the herbs on Amazon, and watch YouTube videos on how to prepare them at home. The result is a growing alternative health sector, which in 2017 saw U.S. herbal supplement sales top eight billion dollars, a 68 percent increase since 2008.

You'll also find doctors who denounce traditional Chinese medicine as pseudoscience and quackery, pointing to some of its most outlandish claims, like the ancient practice of prescribing firecrackers to chase away demons, or mysterious concepts still embraced, such as a nebulous life force called qi (a term translated literally as "the steam that rises from the rice"). Others rail against its use of animal parts and warn against the potential dangers of its herbal formulas.

"Rarely do you find anyone who looks at it objectively," says medical historian Paul Unschuld. A leading authority on the history of Chinese medicine—and often an unsparing critic of the way it's interpreted—he has collected and translated hundreds of ancient medical texts and is working with a Chinese-German startup to study them for ideas about treating a variety of illnesses, including epilepsy. "People generally see only what they want to see," he says, "and fail to fully examine its merits and its faults."

I encountered this hornet's nest firsthand when I wrote a story about rhinos being poached for their horns. According to ancient Chinese formulas, rhino horn can be used to treat fever and headaches. In Vietnam I found patients using it to treat hangovers and the side effects of chemotherapy. Multiple scientific studies have determined that rhino horn, which is made of keratin (the same substance as human fingernails), induces little to no discernible pharmacological effects when ingested. But some patients using rhino horn may find relief because of the placebo effect. After the story was published, I got letters from readers angrily denouncing Chinese medicine as "ignorant," "cruel," and akin to "witchcraft."

Such criticisms aren't without merit. Rhino horn sales in Asia are a primary factor pushing

rhino populations toward extinction. In addition to bears, many other animals—including several threatened species such as tigers, leopards, and elephants—are poached in the wild or farmed for their parts.

But modern medicine has its own controversial practices. The effectiveness of many popular antidepressant drugs remains hotly debated, with some studies showing they are barely more effective than placebos. Yet these drugs are extensively marketed and widely prescribed by physicians, generating billions of dollars in revenue. (This isn't to say depression drugs don't work. If a patient's symptoms are relieved, then one can argue they work. But the chemicals in the pills themselves may not always be the source of the relief, just like the chemicals in rhino horn aren't necessarily the source of relief for patients who take it.) When considered alongside other notable examples—the overprescription of opioids, doctor-endorsed fad diets, and questionable surgeries—Western indignation over traditional Chinese medicine can seem more hypocritical than Hippocratic.

This is where snake oil might offer some illumination. Long synonymous with swindling, snake oil actually refers to a traditional Chinese ointment derived from the fat of the Erabu sea snake. Historians believe that such ointments were introduced to the U.S. during the 1800s by Chinese immigrants building railroads, who used them to treat aching joints and muscles. The substance acquired its shady reputation when American hucksters began selling mineral oil as Chinese snake oil.

But here's the rub: Studies have shown that fat in the Erabu sea snake, an ingredient in some traditional Chinese remedies, contains higher levels of omega-3 fatty acids than salmon. Omega-3s are known to reduce inflammation and harmful cholesterol, improve cognition, and help alleviate depression. They are now used in several skin care products. In the 2000s Japanese scientists fed Erabu fat to mice and observed that their ability to swim and to learn their way around mazes improved.

"Don't throw out the baby with the bath water," Yung-Chi Cheng, a pharmacology professor at Yale School of Medicine, says with a chuckle. "People forget that one of the oldest, most effective, scientifically proven drugs came from traditional medicine—aspirin." The ancient Egyptians used dried myrtle leaves to treat aches and pains, and Hippocrates, the fourth-century B.C. Greek physician, considered the father of Western medicine, prescribed an extract of willow bark for fevers. But it wasn't until the 1800s that European scientists figured out that the active ingredient in both is salicylic acid and synthesized it. Today aspirin, at pennies a dose, is arguably the world's most cost-effective drug.

"It all started with people observing willow bark was effective and then using it to treat illness," Cheng says. "In this case, science followed the medicine, not the other way around."

Aspirin is hardly the only case of a modern drug hiding among traditional treatments. In 1972, the year Cheng finished his Ph.D. in pharmacology at Brown University, a chemist in the People's Republic of China named Tu Youyou announced the discovery of an antimalarial substance based on a Chinese medicinal herb mentioned in a fourth-century formula.

During the Vietnam War, Tu had been tapped to work on a secret military project to help the Vietcong combat malaria. The disease accounted for roughly half their casualties. Western health researchers were also trying to solve this problem, screening more than 200,000 compounds. But Tu wondered if an answer might lie in classical Chinese medical texts. She tested several plants related to fever and found a remedy based on a yellow-flowering herb called wormwood *(Artemisia annua)*. The drug derived from her research, called artemisinin, has been credited with saving millions of lives and earned her the 2015 Nobel Prize for medicine.

MY NOSE IS FREAKING OUT as I follow Cheng on a tour of his labyrinthine lab at Yale, where his team is analyzing the characteristics of a variety of herbs to investigate their medicinal value. Amid the sighs and gurgles of various chemical experiments, I catch whiffs of black pepper, rosemary, camphor, ginger, chili, cinnamon, and other scents I can't identify. The back of my throat tingles. I think I might sneeze. I notice I'm hungry for Thai food.

On his desk, Cheng has a bobblehead doll in his likeness. A gift from the staff, it depicts him in a suit rather than the slightly baggy sweaters he generally favors, but it captures his thoughtful demeanor, receding hair, and large earlobes, which according to Chinese tradition signify longevity. On first impression Cheng may seem like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A shop at a market in Guangzhou, China, specializes in deer parts—including antlers, penises, and tendons—used in traditional formulas. One obstacle to acceptance of Chinese medicine in the West is the controversial use of animal parts.

STEPS TO AN HERBAL REMEDY

1 DIAGNOSE PATIENT

A practitioner identifies a patient's ailment through an extensive examination that can include checking the pulse and tongue.

2 GATHER INGREDIENTS

Each patient is unique: People suffering from the same symptoms may receive significantly different prescriptions.

君 Monarchs

These principal ingredients target the immediate cause and symptoms of the disease.

臣 Ministers

These herbs are said to enhance the monarch's effects and also target underlying symptoms.

佐 Assistants

These treat secondary symptoms, eliminate toxins, and optimize the effects of the other herbs.

使 Guides

Not always necessary in prescriptions, these herbs help deliver ingredients to targeted areas.

HERBS SCIENTIFICALLY SHOWN TO

- FI Fight infection
- RI Reduce inflammation
- RF Reduce fever

Traditional Treatment

Herbal prescriptions, many dating back millennia, are a big part of traditional Chinese medicine. Formulas may consist of a single herb or many and are customized based on a patient's condition, age, gender, and body type. The recipe for mixing Yinqiao, a 10-herb treatment for the common cold, is shown here.

ANCIENT THEORIES

One belief is that the body consists of opposite but complementary qualities, or yin and yang, that maintain its healthy balance. Treatments following the four properties and five flavors are thought to promote balance.

FOUR PROPERTIES

Herbs are labeled hot or cold for their ability to treat ailments considered related to either cold (yin) or heat (yang).

Cold | Cool | Neutral | Warm | Hot

Yin (cold) herbs treat yang (hot) ailments, such as swelling.

Yang (hot) herbs treat yin (cold) conditions, such as chills.

3 PROCESS PRESCRIPTION

Depending on the prescription, an herb may be processed in various ways to extract its healing properties in their proper potency.

The Paozhi (processing) stage distills herbs to their essence by crushing, roasting, burning, or frying to eliminate impurities.

Medicine grinder

The grinder is sometimes used on soft herbs, like mint, the mortar and pestle on hard ones.

Mortar and pestle

The herbs are steadily boiled, often for hours, causing a chemical change believed to blend their healing properties.

Boiling pot

4 TREAT PATIENT

A traditional prescription is designed to target specific parts of the body and to bring the patient's entire system back into balance.

- **Acupuncture point**
- **Meridian** Pathway in the body where energy is said to flow

Traditional and artisanal

The medicine is consumed in a broth or tea of reed roots or applied as a patch at acupuncture points.

Patch

Tea

Premade and standardized

Generic remedies can be sold as pills or in packets, but some say teas from raw herbs are more effective.

Pills

Powder

FIVE FLAVORS

Different flavors are believed to have specific healing properties and the ability to target specific body areas and organs.

Spicy Stimulates sweating, blood circulation

Salty Aids bowel movements

Bitter Reduces heat

Sweet Relieves pain

Sour Stops sweating, coughing, and diarrhea

MONICA SERRANO AND DAISY CHUNG, NGM STAFF; MANYUN ZOU; MEG ROOSEVELT. ART: JIWOON PAK. CALLIGRAPHY: JAMIE WU. SOURCES: NATIONAL CENTER FOR BIOTECHNOLOGY INFORMATION; ZHANG WEI, INSTITUTE OF CHINESE MATERIA MEDICA, CHINA ACADEMY OF CHINESE MEDICAL SCIENCES; LINN YEH CHING

A traditional practitioner at a clinic in Chengdu, China, checks a patient's pulse as others wait. Next he will inspect the tongue and examine other body parts to identify symptoms, then prescribe a treatment to bring the body into balance and help it fight off illness.

RIGHT

Two-month-old Ren Yanyu in Chengdu is bathed in an herbal solution meant to detoxify and cool the body during the humid summer months. The treatment is part of the Chinese philosophy of maintaining the body's overall well-being, not just treating ailments after they've surfaced.

BELOW

At a clinic in Beckley, West Virginia, Jeff Hendricks receives acupuncture and a plant-burning technique called moxibustion to ease pain related to four years of military service. He suffers from a brain injury, bulging disks in his neck, bone spurs, headaches, numbness in his hands, and PTSD. The VA-approved treatment reduces the need for conventional drugs.

a stereotypical advocate for traditional Chinese medicine. Though he's been in the United States for five decades since emigrating from Taiwan, he still speaks English with a strong accent, and at 74, he comes from a generation of Chinese that still has a deep attachment to many of the old traditions. "But I didn't really know much about Chinese medicine," he says, noting that as a child, his parents took him to doctors practicing science-based medicine.

Cheng has focused his research solidly in the realm of science, developing antiviral drugs for chronic diseases, such as hepatitis B. But he has also wondered whether there were other cures, based on herbs like wormwood, awaiting rediscovery. Now he's found one that may prove a breakthrough in cancer treatment. He opens a jar and hands me a pinch of a powder—a mixture of four herbs he calls PHY906.

"Taste it," he says. I put a tiny bit on my tongue. It's bitter, with hints of licorice.

During the 1990s Cheng noted that many cancer patients stopped chemotherapy because of its side effects, including diarrhea and severe nausea. Patients who completed the full course of chemotherapy tended to live the longest, so curbing the side effects, Cheng reasoned, could increase life expectancy. He also knew that Chinese medicine had many herbal treatments for diarrhea and nausea.

His colleague Shwu-Huey Liu, an expert in pharmaceutical chemistry who's fluent in classical Mandarin, searched the Yale library's large collection of early Chinese medical texts. In an ancient book titled *Treatise on Cold Damage,* printed on slightly wrinkled bamboo paper, she found an 1,800-year-old recipe for a mixture of skullcap, licorice, peony, and Chinese date, described as a treatment for "diarrhea, abdominal pain, and scorching heat in the anus."

Cheng's team began trying different blends of the herbal formula. Over the past 20 years, they have proceeded from tests on mice to patients undergoing cancer treatment, overseen by the National Cancer Institute. As Cheng had hoped, almost all the patients who took the herbal formula experienced relief from nausea and other gastrointestinal distress, but something else happened: Their tumors shrank faster than those of patients who hadn't taken the herbal formula.

"I didn't expect that," Cheng says. "So now the question is, Why?"

Johnson & Johnson and Bristol-Myers Squibb, both major producers of cancer drugs, also would like to know the answer. At a pharmaceutical conference in Philadelphia, I listen as Cheng's son Peikwen explains to representatives from those and other leading drug companies what is known about how PHY906 works. A Stanford University graduate who also has an MBA, Peikwen, 43, joined his father to form a company to market PHY906 and develop other herbal drugs. He's dressed in a trim charcoal suit, and his fluency in Mandarin, medical terminology, and Silicon Valley argot equip him to bridge the worlds of Eastern and Western medicine and make him a persuasive advocate.

After analyzing tumors in mice that were given the formula, Peikwen says, researchers noticed a significant increase in tumor-eating macrophages—white blood cells that gobble up cancer cells. The way the herbs interact appears to be the key. "That's really where the frontier lies," Peikwen says. "PHY906 is a cocktail of chemicals—not unlike the drug cocktails that finally proved effective for AIDS patients. We're just unraveling

the original formula and putting it back together in a modern, scientifically based therapy."

To date PHY906 has been used in eight human trials alongside different chemotherapy drugs and radiation to treat colorectal, liver, and pancreatic cancers, Peikwen tells the audience. "We are hopeful that PHY906 will become the first FDA-approved, multi-herb drug."

Afterward, several pharmaceutical reps pull him aside to speak privately.

PEIKWEN AND I HURTLE into the heart of China on a modern bullet train. The ride is remarkably smooth, as if we're floating above the track. Meanwhile, ancient China flashes by, an endless patchwork of farms under a gray winter sky. Peikwen agreed to let me visit the source of the herbs if I wouldn't reveal the full names of the farmers or their locations, which he and his father, along with their partner Sun Ten, a Taiwanese pharmaceutical herb company, consider proprietary information.

I can say this part of China looks like a version of Kansas—tabletop flat with neatly furrowed fields as far as I can see. But among the wheat, rice, and rapeseed are plots of herbs tended by thousands of farmers. As the global appetite for herbal remedies has grown, Chinese farmers have devoted increasing amounts of acreage to hundreds of medicinal plant species. In 2017 the nation's medicinal herb-growing industry generated about $25 billion.

But before you quit your job to farm herbs, here's the problem: Producing medicine-grade herbs is extraordinarily difficult. The chemical potency of each herb can vary greatly, depending on many factors—minerals in the soil, the altitude at which it's grown, when and how it's harvested. And then there's the matter of subspecies that may look exactly alike but have slightly different chemical compositions.

Ask a pot smoker about the difference in potency from one marijuana strain to the next, and you'll get an earful. Or ask a coffee grower: Arabica beans grown in one part of Ethiopia can have six times as much caffeine as those grown in another part of the country. And depending on how they're ground and brewed, the same beans can yield different caffeine amounts.

These complications are part of the reason that the FDA has approved only two herbal prescription drugs—a genital wart treatment made from green tea extract and a diarrhea medicine made from the sap of the South American dragon's blood tree. Both those drugs contain a single herb, but PHY906 is composed of four, which means more variables must be controlled to make a consistent product. "This complexity is partly why there aren't any FDA-approved, multi-herb drugs," Peikwen says.

When we finally get to one of the fields that yielded PHY906, I'm frankly a little disappointed. Except for the fact that the farmer, Chen, is speaking Mandarin, he might as well have been from Kansas. Wearing muddy boots, a heavy parka, and a baseball cap, he pulls out his iPhone and asks Siri to translate the Chinese name of his crop into English. "Peony," she answers.

As we tour his fields of peony and skullcap bushes, he explains his crop rotations, soil and water analyses, planting and harvesting protocols. Before shipping the herbs, he says, technicians from Sun Ten perform multiple tests to reconfirm the species; screen for microorganisms, toxins, and heavy metals; and complete other quality checks.

In a fire treatment session in Chengdu, an alcohol-soaked cloth is draped over a patient and set alight to warm the skin and open the pores; an herb-infused oil is then applied. The therapy aims to treat joint pain and other ailments, but research has yet to prove such claims.

"You've heard of farm to table," Peikwen says. "The idea here is farm to bedside."

I tell him that sounds like a marketing slogan. But it's true, says Chen. "Most companies making herbal remedies don't get them from farms like this. They get them from Bozhou."

IF YOU BUY CHINESE HERBS on Amazon, there's a decent chance that they passed through the eastern city of Bozhou, the center of the Chinese medicine universe. Every day 10,000 traders sell thousands of different products to 30,000 buyers from all over Southeast Asia, all of them jammed in a colossal structure resembling a domed football stadium.

The morning I visit Bozhou, the market is already a raucous hive of commerce. I zigzag up and down endless aisles, one cavernous room after another, each chock-full of barrels, sacks, pallets, and wheelbarrows heaped with wares derived from what appears to be nearly every plant, mineral, and creature on the planet, including exotic items like deer penises, human placentas, water buffalo bones, and dried seahorses. A section the size of a grocery store is devoted to the cure-all ginseng root—red and white, wild and cultivated, fresh and dried, ranging in price from a few dollars to several thousand. In the insect section, I stop counting the different centipede species at 11.

I've come here to see the source of most Chinese herbal drugs marketed around the world. You can find seemingly every ingredient here, but you'd have little clue how it was grown or where. Sure enough, I easily find all four ingredients for PHY906—but all are sold by resellers who know little of the herbs' origins.

Before I leave the market, one ingredient catches my eye. In a section near deer antler velvet, I see a glass case with a row of bottles containing yellowish liquid. I ask the vendor what it is, and he gets his neighbor to translate. "Take from bear," the man says. "Very good."

PAUL IAIZZO LOVES BEARS. An avid outdoorsman who grew up in Minnesota, he has long

Apothecaries at Chengdu Tongrentang traditional pharmacy fill herbal prescriptions, dividing the mixtures into single doses that are folded into paper envelopes. At home, patients will brew them into a tea to drink.

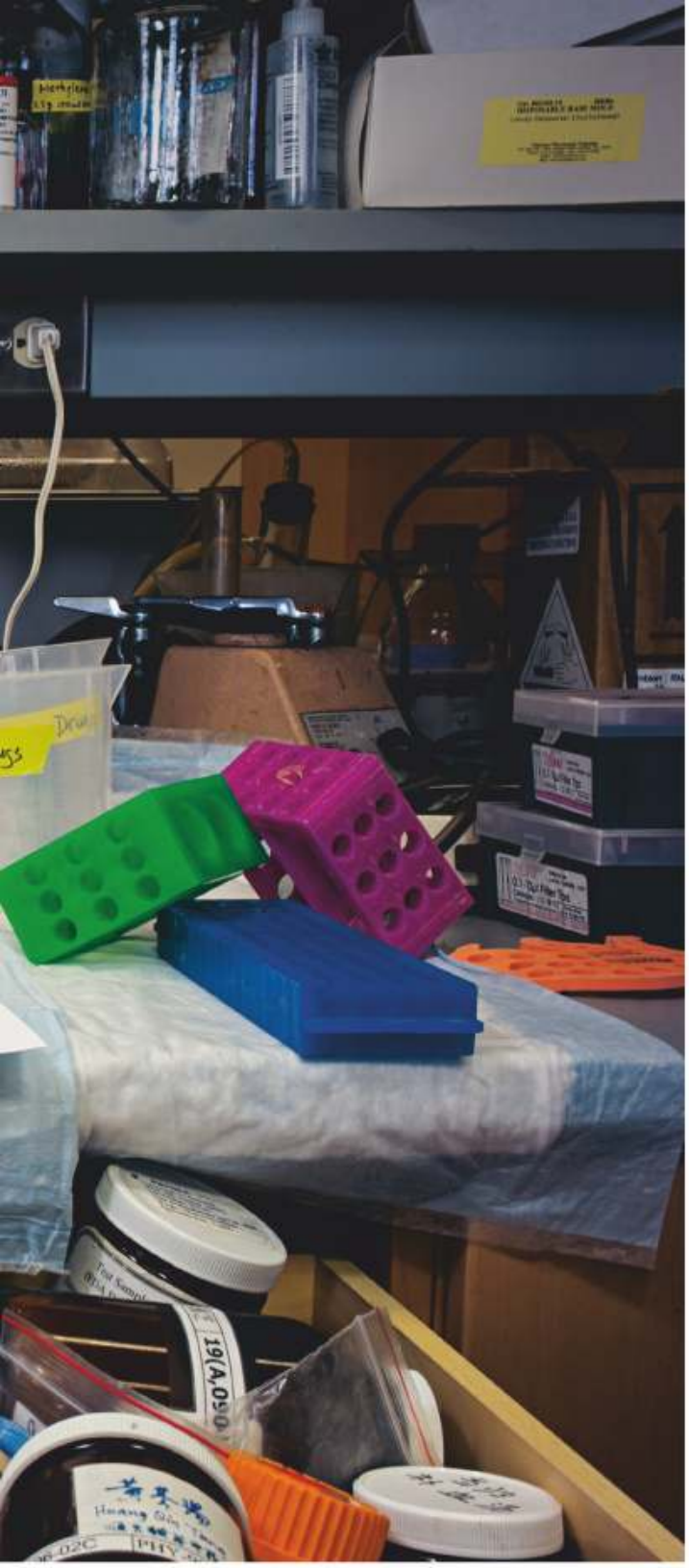

谷精草
半边莲
相思子
大风子
酸枣仁
艾叶
络石藤
刘寄奴
仙鹤草
蒲公英
猪牙皂
肉桂子
黄荆子
金果榄
山豆根
一朵云
丁香
苏木
浮小麦

been fascinated by the animals, which roam the state's forests. As head of the University of Minnesota's Visible Heart Lab, he's especially interested in their unique physiology and has teamed up with the state's Department of Natural Resources to study how they hibernate.

Tall and lean, with a mane of silver hair, Iaizzo ticks off a list of mysteries related to bears, which spend up to six months completely inactive yet suffer no ill effects. Their breathing slows to as few as two breaths a minute. Their temperature drops by 10 percent, which would cause hypothermia in a human. They regularly lose more than half of their body fat but no muscle. Their hearts can pause for 20 seconds, but their blood never clots. Humans risk deadly clots if their hearts pause for only a few seconds. And yet if a predator approaches, a bear can wake up to defend its den. "And its heart suffers no damage," Iaizzo says.

The earliest mention of bear bile in Chinese literature turns up in a 40-volume treatise from the eighth century called *The Medical Secrets of an Official*. It prescribes bear bile for liver problems, as well as fever, hemorrhoids, and other ailments. In 1902 a Swedish scientist isolated one of the chemicals in bear bile, later named ursodeoxycholic acid, and it's now used in drugs for liver diseases and gallstones.

But Iaizzo and other researchers believe there are many more secrets to be revealed from bear bile, which is produced by the liver, stored in the



Cheng's team grew this *Ganoderma tsugae* fungus in the lab. The species has been found to shrink colorectal tumors in animals. "The Chinese have used herbs for centuries," Cheng says. "The challenge to scientists is to find out which formulas work, and why."

gallbladder, and secreted as hormones into the bloodstream. They are taking aim at a range of therapies, including treatments for muscular dystrophy and for bedridden patients who can lose half of their muscle mass in three weeks.

He's identified three classes of bile components that likely trigger hibernation and may help heart patients—fatty acids, bile acids, and delta opioids. During the procedure on the pig, he injected a synthetic mixture of these into the protective membrane around the beating heart to coat the organ for an hour before he removed it.

Over hundreds of experiments, he's seen pig hearts—which are very similar to human hearts—last up to twice as long as they usually do outside the body. There are many possible applications for humans. Most notably, hearts from donors could be kept viable longer and, once inside a recipient, could be restarted faster. Currently, a heart must be transplanted within six hours or less. In the U.S., 300 people die every year waiting for hearts.

"If we could preserve a heart for 24 hours, we could get it anywhere in the world," Iaizzo says. "And that could vastly increase the number of available organs. That would be a game changer."

I ask him whether the Chinese practice of drinking bear bile could really bestow any health benefits. "It could," Iaizzo says, noting the chemicals would enter the bloodstream and move through the heart and other organs. He doesn't condone farming bears for their bile, emphasizing that the chemicals can be synthesized, but the science is the science. And though the ancient Chinese didn't understand how bear bile helped humans, they observed that it did.

As I hold the pig heart, I can feel its rhythm slowing. It finally stops. The pig died hours ago, and now its heart has stopped too. Its color seems to dim—like a mahi-mahi that loses its lightning yellow glow as it dies in the hands of a fisherman. I wonder if whatever is now gone is what the ancient Chinese meant by qi.

I think of the moment in the hospital when I was holding my father's hand and felt his pulse finally stop. I'm suddenly aware of my own heart, flexing and lurching inside my rib cage, and wonder about its other mysteries. □

Peter Gwin wrote about falconry in the October 2018 issue. **Fritz Hoffmann** has been photographing stories in China for 25 years.

GIVING LIFE CAN STILL BE DEADLY

The U.S. is one of only two developed countries where the rate of **women dying from pregnancy** has gotten worse since 1990. **Black mothers** are particularly at risk. Better basic care could help, as it has in the developing world.

BY RACHEL JONES

PHOTOGRAPHS BY LYNSEY ADDARIO

Casey Otto Haubelt greets the world after he was delivered by cesarean section last June at the Texas Children's Hospital Pavilion for Women in Houston. Loren Denise Haubelt, 30, required an emergency hysterectomy after Casey's birth to address placenta increta, a condition in which the placenta grows into the uterine muscle.

At 34 weeks pregnant, Brittany Capers, 28, and DeAndre Price, 25, enjoy their baby shower in Washington, D.C. Capers is a perinatal community health worker at Mamatoto Village, a center that supports families during pregnancy and the first six months of a baby's life. She safely delivered a baby boy last June.


DADDY'S LITTLE
HERO

Surrounded by photos of his late wife, Kira Johnson, Charles Johnson IV, 37, plays with their children, Charles V, three (in lap), and Langston, two, at home in Atlanta, Georgia. Following an uncomplicated pregnancy, Kira died from internal bleeding 12 hours after delivering Langston by C-section.

KIRA JOHNSON, PREGNANT WITH HER SON LANGSTON

There are times when flip-flops and sweatpants seem appropriate. At a Saturday afternoon picnic in the park. Or at the county fair. Or when you're a couple preparing for the arrival of Baby Number Two. Comfort is key.

But something made Kira Johnson, 39, change her mind on the evening of April 11, 2016.

"Babe, I want to look really pretty for Langston," she told her husband, Charles Johnson IV, as she sat before her bedroom mirror brushing her hair. The next afternoon they would head to Los Angeles's Cedars-Sinai Medical Center for the birth of their second son.

They were committed to raising "men that would leave a mark on the world and who have a sense of purpose and responsibility far beyond themselves," Charles explains.

Baby Number One, born in 2014 by emergency cesarean section, was named Charles Spurgeon Johnson V, after his great-great-grandfather, the famed sociologist and first black president of Fisk University in Nashville, Tennessee. His little brother would be named after the legendary Harlem Renaissance poet Langston Hughes. Kira packed jewelry and a dress so she could bring him home in style. Charles decided he needed to dress the part too. "You never know when you need to look like you have a little bit of sense and a little bit of money," Johnson recalls thinking, as he scrapped the basketball shorts and T-shirt for a button-down shirt, slacks, and loafers.

The choice was as mindful as the selection of Cedars-Sinai, consistently ranked among the best hospitals in the United States. When you have all the other bases covered—a healthy mom, a healthy baby, the best prenatal care available—why not put the icing on the cake by having your baby at a world-class facility?

Langston Emile Johnson was born at 2:33 p.m. on April 12, 2016. The scheduled C-section seemed routine, and Kira was able to breastfeed just after giving birth. She helped introduce Langston to his 18-month-old brother before drifting off to sleep.

Charles was sitting beside his wife's bed when he noticed blood in her catheter. It was after 4 p.m. when he first told a nurse about it, according to a complaint Charles filed in 2017 with a lawsuit he brought against Cedars-Sinai. Also included in the complaint are details about the care Kira received: The catheter was changed at

COURTESY CHARLES JOHNSON IV

about 5:30 p.m. and was followed by an ultrasound and blood work. The ultrasound showed signs of internal bleeding. Pain medication and intravenous fluids were administered. A CT scan was ordered at 6:44 p.m. Ultrasounds and blood work were repeated. A blood transfusion was given. Another four hours and still no CT scan. Another blood transfusion was given, according to the complaint. Kira was "pale and groggy," Charles says, adding that she was "shivering uncontrollably." Her abdomen was painful to the touch. Charles says he repeatedly asked hospital staff what was being done to identify the source of her bleeding.

"As a father and a husband, there's a fine line between trying to advocate for your wife and crossing a line, particularly as a black man," he recalls. Charles says he did not want to do anything that would be detrimental to his wife's care.

Especially, Charles says, after one staff member answered his anxious query by saying, "Sir, your wife's just not a priority right now."

The CT scan never happened, according to the complaint. Kira was taken into surgery around 12:30 a.m., 10 hours after the C-section. Her abdomen was full of blood. Her last words to her husband, he says, were, "Baby, I'm scared."

His wife's fear rattled Charles, because bravery defined her: Kira had lived in China, spoke five languages, had a pilot's license, and had driven race cars. But he assured her everything would be OK.

Kira died at 2:22 a.m. on April 13.

"'We did everything we could to save your wife, but we couldn't save her,'" Charles recalls the doctor telling him. It was "like watching my whole world crumble around me. It was like a bomb went off, and I see her mother fall on the floor, her aunt screaming, her brother just breaking."

"We were so prepared. We had this. We had the best of everything. We did everything right. And they're standing there telling me they lost her?" Charles says.

According to the complaint, the autopsy determined that Kira died of internal bleeding after her C-section. Racial bias is not part of the complaint. A trial is scheduled for January. In October, the Medical Board of California found Arjang Naim, the attending physician who oversaw Kira's care, to be grossly negligent. Naim said Kira Johnson's death was unfortunate, adding that he did not expect her to pass away on the operating table during surgery. "I did as much as possible to take the best care of the patient," he said. Naim was put on probation for four years.

A hospital spokesperson would not comment on the specifics of the case but said in a statement that "Kira Johnson's death was a tragedy. We thoroughly investigate any situation where there are concerns about a patient's medical care. Based on our findings, we make any changes that are needed so that we can continue to provide the highest quality care to our patients. This includes reviewing hospital procedures as well as the competency of health care providers."

KIRA'S DEATH WAS SHOCKING BUT underscores a harsh reality: At a time when the pace of medical advances can be breathtaking—from genetic testing that can predict the likelihood of conditions to treatments that have never been more effective in targeting cancer and other diseases—the rate of maternal deaths remains stubbornly high in the United States: about 14 deaths for every 100,000 live births. Among 46 developed nations, the World Health Organization says, only Serbia and the United States had maternal death rates that worsened between 1990 and 2015. This rate includes mothers who die of complications within six weeks of the end of the pregnancy.

In the United States the problem is marked by two particularly alarming statistics: African-American women are about three times as likely to die of pregnancy-related causes as white women, and more than 60 percent of maternal deaths are preventable, according to the Centers for Disease Control and Prevention (CDC).

"We have higher maternal mortality than much of the rest of the developed world; we are capable of doing the best in the world," says William Callaghan, the CDC's chief of maternal and infant health. The CDC defines a pregnancy-related death as a woman who dies while pregnant or within one year of the end of her pregnancy.

"When deaths are reviewed and we see what the contributing factors were, there are so many instances where communication was not carried out correctly, where people didn't recognize urgency, or when the patient wasn't listened to, or the delay in reaction."

The maternal mortality rate for the United States remains far below those of developing nations in Africa, where 20 countries have maternal death rates of at least 500 deaths for

every 100,000 live births. But even in those countries, where medical facilities and access to basic care often are lacking, maternal mortality rates have declined since 1990 by an average of almost 40 percent, thanks in part to low-tech solutions such as midwives and improvements in prenatal and postpartum care.

All women are vulnerable to the same pregnancy-related health conditions that can lead to death: postpartum hemorrhage, or excessive bleeding; preeclampsia, or dangerously high blood pressure; and sepsis stemming from an infection. So why are the maternal mortality rates for African-American women so high?

Researchers say the toxic stress that racial and ethnic minorities, including African Americans, Latinos, and Native Americans, experience—regardless of economic or social success—can erode their physical health. It's known as "weathering," a concept developed by University of Michigan professor of public health Arline Geronimus that suggests the health of African Americans deteriorates earlier than that of whites because of the cumulative effects of racism and bias. It may help explain why even black mothers with the highest levels of education are dying at higher rates than white women with the least education.

Valerie Montgomery Rice, president and dean of the Morehouse School of Medicine in Atlanta, Georgia, believes that not only does bias and racism build up to affect the health of black women over time, but that stress from racism and poverty may have adverse effects as early as in utero or soon after a baby is born.

She also points out that unconscious bias from medical providers can affect the care black mothers receive. While training at Grady Memorial Hospital, she saw that providers would occasionally withhold epidurals and local anesthetics from African-American women. "You have people who believe that black women don't experience pain the same way because they have higher muscle mass, that their pain fibers don't fire as much. 'That woman can push that baby out—she's a big girl.'" Summing up, Montgomery Rice says, "They didn't see the person in their totality."

IN DEVELOPING COUNTRIES, maternal deaths are vastly more prevalent and an accepted fact of life. Health care infrastructure is often sparse or nonexistent. Quality prenatal care and pregnancy information can be limited.

Red capes identify graduates of the midwife training program at the Edna Adan University Hospital in Hargeisa, Somaliland. The program has graduated 938 midwives so far, including Hoodo Mohamed Mohamoud, 18 (at left), Hoodo Mohamed Jama, 20 (middle), and Hodon Abdi Shire, 28 (right), who will work as midwives in their home regions.

More than 9,000 miles from Los Angeles, the dusty highway between Somaliland's capital, Hargeisa, and its third largest city, Borama, pierces the horizon like an arrow. The landscape is dotted sparsely with thorny acacia trees, and the sun beats down like a drum.

Venture off the paved surface, and the only roads are rocky and perilous, sure to scar the undercarriage of all but the sturdiest utility vehicle. It's hard to imagine a woman in labor surviving the journey, in a vehicle or on foot, from a remote rural area to a health facility. Somaliland is a self-declared nation in the Horn of Africa, though it is widely viewed internationally as an autonomous region within Somalia.

The main causes of maternal deaths in

Somaliland are eclampsia (seizures or convulsions due to high blood pressure), hemorrhage, infection, and ruptured uterus. Other reasons include early or too many pregnancies, unassisted deliveries, and complications from female genital mutilation (FGM), a practice of removing external genitalia of girls and women in order to make them "pure" and suitable for marriage. The scarred tissue can narrow the birth canal, complicating childbirth.

In Somaliland, consent for C-sections or any kind of lifesaving procedure, including a blood transfusion or surgery, has to be obtained from a male relative financially responsible for a woman's health, such as her husband or a man from her husband's side of the family.

THAT IS THE LANDSCAPE into which Edna Adan Ismail, the eldest of three children in a wealthy family, was born.

Her father, Adan Ismail, was the most senior Somaliland health professional in the former British protectorate, which declared its independence in 1960. Of her mother's five deliveries, one girl died during a forceps delivery in a hospital, a procedure that had almost killed Adan. Another died after being dropped on his head by a midwife.

Education traditionally was considered useless for girls, but Ismail encouraged it for all his children. He was furious upon returning home from a business trip when Adan was about eight years old to learn that her mother and grandmother

Feeling dizzy and weak six months after giving birth, Zamzam Yousuf, 35, came into a clinic in the village of Habasweyn run by the Edna Adan University Hospital. Her blood pressure was extremely high. Yousuf was treated by student midwife Farduus Mubarak, 22, under the watchful eye of the hospital's founder, Edna Adan Ismail, 81.

A mother of seven, Ayesha Ciisa, 33, arrived at Borama Regional Hospital in Somaliland near death after delivering one of two twins at home. She came to the hospital by auto-rickshaw when the second baby could not be delivered in her village. Despite Ciisa's severe bleeding, doctors were able to save her with a transfusion. The second baby was stillborn.

MOTHERS AT RISK

The United States struggles with pregnancy-related deaths, many of which are preventable. The causes range from a rise in pregnancy-related medical conditions and the age of women giving birth to a lack of standardized protocols across hospitals. The U.S. fares better than most developing nations (Sierra Leone has the world's highest maternal mortality rate, at 1,360 deaths per 100,000 live births) but is one of only two developed nations whose rate has worsened in recent decades.

Romania in 1990 had 120 maternal deaths per 100,000 live births.

MATERNAL MORTALITY RATE

The rate is calculated as the number of maternal deaths while pregnant or within 42 days of the end of pregnancy, for every 100,000 live births.

IN DEVELOPED COUNTRIES

Ages 15 to 49

1990
2015
COUNTRY

MORE DEATHS
FEWER DEATHS
NO CHANGE

70
60
50
40
30
20
10
0

THE OUTLIERS

The U.S. and Serbia are the only developed nations whose maternal mortality rates have increased since 1990.

*The 2015 **U.S. rate** was 14 maternal deaths per 100,000 live births.*

UNITED STATES
SERBIA

GREECE
FINLAND
SPAIN
CANADA
ICELAND
NORWAY
AUSTRALIA
AUSTRIA
ITALY
SWEDEN
SWITZERLAND
BELGIUM
CROATIA
MONTENEGRO
UNITED KINGDOM
DENMARK
GERMANY
IRELAND
ISRAEL
SLOVAKIA
LUXEMBOURG
NETHERLANDS
SLOVENIA
MALTA
CZECHIA
JAPAN
MACEDONIA
FRANCE
CYPRUS
POLAND
PORTUGAL
NEW ZEALAND
HUNGARY
BULGARIA
BOSNIA AND HERZEGOVINA
LITHUANIA
BELARUS
ESTONIA
LATVIA
UKRAINE
MOLDOVA
RUSSIA
ALBANIA
ROMANIA

MATERNAL MORTALITY BY U.S. STATE

Average rate, 2011-2015
All ages

WESTERN
CENTRAL
EASTERN

60
50
40
30
20
10
0

GA
LA
IN
NJ
DC
AR
TX
MO
SD
SC
NM
WY*
MT
FL
MD
OK
TN
MS
ID
NY
OH
KY
MI
ND
IA
KS
NE
IL
AZ
RI
NH*
PA
NC
ME
VA
UT
WA
OR
WI
DE*
CT
MN
HI
CO
AL
WV
NV
MA
CA

THE WORLD HEALTH ORGANIZATION MAY ADJUST U.S. AND OTHER NATIONS' DATA TO ENSURE COMPARABILITY AT THE GLOBAL LEVEL. *DE, NH, AND WY DATA 2005-2015. DATA UNAVAILABLE FOR ALASKA AND VERMONT.

MONICA SERRANO, NGM STAFF; KELSEY NOWAKOWSKI. SOURCES: "TRENDS IN MATERNAL MORTALITY: 1990 TO 2015," WHO; CDC; "BUILDING U.S. CAPACITY TO REVIEW AND PREVENT MATERNAL DEATHS"; AMERICA'S HEALTH RANKINGS

had arranged for her to undergo FGM.

In 1954, at 17, Adan left Hargeisa to train as a nurse and midwife in London, England. Adan wanted to prevent girls and women from experiencing the trauma she endured during and after receiving "the cut," as she calls FGM.

Now 81, Adan will tell you that her greatest achievement was not when she was Somaliland's first female cabinet member. Her ultimate fulfillment comes from living at the Edna Adan University Hospital in Hargeisa as its on-site administrator. She rises every day before dawn and will not refuse a 9 p.m. meeting if it's in service of her maternity hospital.

Adan says she begged, borrowed, and used her savings and pension to build the hospital.

"The two main killers of pregnant women are poverty and ignorance," Adan says, striking a regal pose from behind her desk. "A combination of those two kill more women than eclampsia or postpartum hemorrhage. So when you have a woman who's illiterate, who's poor—in Somaliland she's also likely to be a nomad—she's also lived a life where she's never had any social justice. Superimpose on that a pregnancy that may have arrived when her body was not fully ready to receive a pregnancy. We delivered a woman here who was having baby number 21."

Or she may be like the mother of the midwife and chief anesthetist at Edna Adan University Hospital, 27-year-old Hamda Omar Mohammed.

Omar's mother, Samsam Mohammed, cooked for the construction crew as the hospital was being built in 2002, and Adan struck up an acquaintance. When Mohammed was not at her usual spot one day, Adan wondered why.

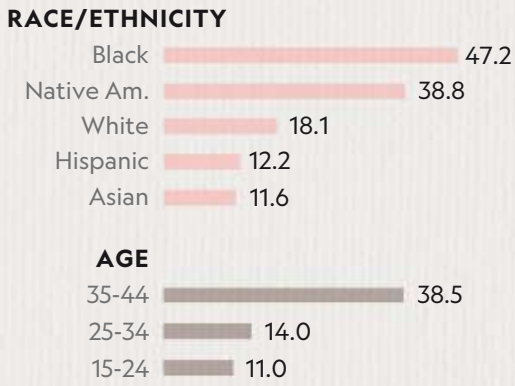
Mohammed was at home, bleeding nearly to death. A neighbor who had come to help had pulled on the umbilical cord when trying to deliver the placenta. The cord became detached, and Mohammed began to bleed. Mohammed's husband ran to get help. Omar, then 11 and the eldest child of four, stayed behind to clean up the blood and look after her siblings. Adan arranged transportation to a government hospital, even donating her own blood to help save Mohammed.

Omar's mother survived. Years later Adan persuaded that traumatized girl to become a midwife, one of the 938 she has helped train in Somaliland so far. "If I can help train a million midwives on the African continent, it will change the experience of childbirth. It will end the suffering for so many women and families."

WHICH AMERICAN WOMEN ARE DYING

Black women are 2.6 times as likely to die due to a pregnancy-related cause as white women. Older women also face greater risk.

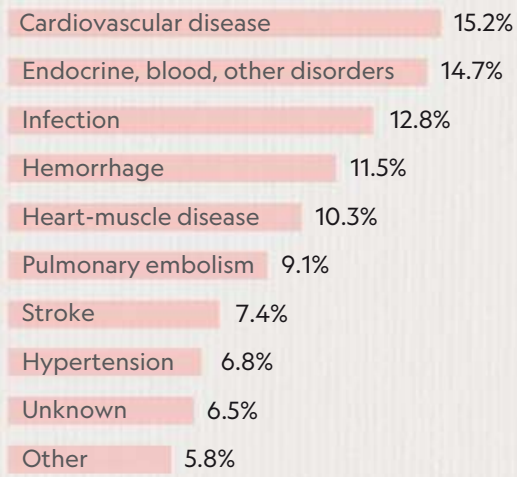
U.S. deaths per 100,000 live births, 2011-2015



HOW THEY'RE DYING

Heart-related problems are a leading cause of maternal death; heart attack risk increases with obesity and age.

2011-2014



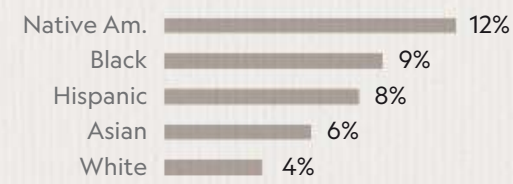
WHEN THEY'RE DYING

Risk doesn't end when pregnancy ends. Potentially fatal post-pregnancy complications include blood clots and hemorrhages.

ACCESS TO PRENATAL CARE

Women with no prenatal care at all are up to four times more likely to suffer a pregnancy-related death.

Women with no care or only third-trimester care



RACE (WHITE AND BLACK) EXCLUDES PEOPLE OF HISPANIC ETHNICITY. HISPANIC INCLUDES HISPANICS OF ALL RACES. ASIAN INCLUDES PACIFIC ISLANDERS. NATIVE AMERICAN INCLUDES ALASKA NATIVES.

OVER THE *SWOOSH, SWOOSH* sound of a fetal monitor, Jontelle Gallman's voice is surprisingly calm. The Washington, D.C., native checked into the George Washington University Hospital on a cloudy Tuesday morning in May, three days after heavy rains flooded her two-bedroom home. Gallman, 39, spent the weekend before her scheduled induced delivery searching for a new place to live.

The mother of three had maintained steady employment as a retail clerk and manager in the two decades since high school, often working 50-hour weeks and providing a good life for her family until 2015. Soon after, doctors diagnosed her with polycystic kidney and liver disease, a chronic genetic condition that causes cysts to grow in those organs.

Too sick to work and relying on Medicaid, the U.S. assistance program that provides health coverage to those with low incomes, Gallman was in the late stages of pregnancy with her fourth child when doctors identified a problem she'd faced previously: dangerously high blood pressure. Without a car and with meager finances, she depended on public transportation and support from friends and family to get to medical appointments and care for her children.

"I just felt like as hard as I had worked to keep things together, life was trying to defeat me," she says. "But I wasn't going to let that happen."

Standing in Gallman's hospital room through

Dionne McDonald, 33, a perinatal community health worker at Mamatoto Village, helps Magan Strawn, 26, by providing counter pressure to the sacrum during labor at the George Washington University Hospital in Washington, D.C., last May. Strawn credits McDonald with helping her avoid an emergency C-section.

most of the 12 hours of her labor and delivery, I couldn't help thinking about my own mother, Eloise Blocker Jones. I am the ninth of her 10 children and one of the only three born in a hospital. We all had been born in poverty in Cairo, Illinois, a small town where the Ohio and Mississippi Rivers meet that is known for its tumultuous racial history.

When Mama died in 2005, it never occurred to me that I would one day want to ask her about her pregnancy and childbirth experiences. After all, she had done her best to drum independence and self-sufficiency into each of her five daughters. Pregnancy before marriage was unthinkable, but to hear Mama tell it, it wasn't exactly a picnic afterward either. I long to ask my mother how she felt as a 19-year-old about to deliver my eldest brother in 1947, far away from her family and friends in Philadelphia. Now I wonder how she endured as a poor woman with no family planning advice, no parenting education, no health insurance.

When Gallman's Medicaid case manager recommended that she contact the Mamatoto Village maternity-support organization in Washington, D.C., she thought she might be able to get some nutritional advice that could improve her diet and boost her energy.

What Gallman got was a lifeline in the form of a perinatal community health worker named Briana Green.

The 39-year-old former corporate lawyer with a waist-length ponytail and a ballet dancer's stride now enters Labor and Delivery Room 8 and heads straight for Gallman's belly, rubbing it gently while also reaching for her hand.

"How are you holding up?" she asks, peering intently at her client through eyelids strained from lack of sleep. At any given time, Green works with about 50 pregnant or postpartum women, making home visits and offering counseling, education, and support. She accompanies them to doctor's visits and is present during delivery.

Green may have been destined for this life: Her great-grandmother Nancy Gayles Burton had 17 children and was a revered granny midwife in Mecklenburg County, Virginia, in the 1920s and 1930s.

Green says she gave up a six-figure income in law and later selling real estate to train as a perinatal-support worker because of her own birth experiences. She says she was denied the opportunity to try for a vaginal delivery after a cesarean section, even after following guidelines to ensure she was physically prepared.

"I realized that if I, as an educated African-American woman with some financial security, couldn't be seen or heard or respected, what about women who didn't have a voice, who were probably being dismissed and mistreated from the minute they entered a health care setting?"

JESSICA FLOWERS is only seven years old, but she's strong, her grandmother Nicole Black says. Black will never forget how calm the little girl was when she called at 1:46 a.m. on July 4, 2018.

"She said, 'Mommy's fallen over in the tub, and she has foam coming out of her mouth,'" recalls

Cindy Lopez, 28, grimaces in pain after the premature birth of her third daughter. She required lifesaving surgery after her C-section delivery to address complications she developed during her pregnancy, including placenta percreta, in which the placenta grows through the uterine wall and can attach to other organs.

Black, who's 53 and lives in Tampa, Florida. A week earlier, Black's daughter, Crystle Galloway, had delivered her third child, a healthy six-pound, four-ounce boy named Jacob Flowers, by cesarean section at St. Joseph's Hospital.

Black scrambled out of bed and over the short distance to Galloway's apartment, where the 30-year-old mother was slumped over the bathtub.

Just a few hours earlier, Galloway had been sitting on the couch watching a movie and talking about the Fourth of July menu. She'd had a bit of pain from the C-section incision, but otherwise Galloway had been so happy, so proud to complete her family of two girls by adding a son.

Exactly what happened in the minutes between when fire medics, dispatched for a possible stroke victim, according to a Hillsborough County, Florida, official statement, arrived at Galloway's home and when she was evaluated at an emergency room three blocks away was the focus of an investigation by Hillsborough County officials.

Black says that instead of checking Galloway's vital signs and transporting her to a hospital, the medics asked whether her family could afford to pay the $600 ambulance fee. Black says that she begged medics to take her daughter in the ambulance.

At a press conference, Hillsborough County Administrator Mike Merrill said that there was confusion about transport and that a conversation about cost was between Black and sheriff's

Nicole Black holds her grandson Jacob Flowers. A week after Jacob's birth by C-section, his mother, Crystle Galloway, developed complications. Black called 911, but her daughter was not transported to the hospital by ambulance. Black drove her there instead. Galloway died five days later. Black's hand rests on the urn containing her daughter's ashes. The responding medics were disciplined for not following standard operating procedures, and one was fired.

deputies who arrived first on the scene and not with medics, according to the medics' and deputies' statements. Merrill also noted that fire medics admitted that Galloway nodded yes when they asked her directly if she wanted to be transported to the hospital. Merrill said the medics should have obtained an informed refusal document for them not to take her in the ambulance, and that did not happen. Black wound up driving her daughter to the emergency room. Galloway then was taken by helicopter to Tampa General Hospital, where she slipped into a coma. She died five days later.

Hillsborough County announced in September that it had taken disciplinary action against the four medics for violating standard operating procedure by failing to check Galloway's vital signs, for falsifying documents, and for not having Black sign an informed refusal document for declining the ambulance ride for her daughter.

One medic was terminated; two were demoted. The three medics still on staff were suspended without pay for 30 days.

BETTER AND SUSTAINED health care support during mothers' pregnancies and after they give birth seems a logical solution to help lower U.S. maternal mortality rates, but it's not that simple. Doulas and midwives can charge upwards of $1,500 for their services, and many low-income mothers simply can't afford that. California has made progress reducing the number of maternal deaths in the state by adding routine protocols at participating hospitals for common pregnancy complications such as hemorrhage and preeclampsia. Procedures such as measuring blood loss or administering high-blood-pressure medication when needed to prevent preeclampsia are part of a set of practices that medical facilities sometimes ignore or delay.

And as Charles Johnson says, simply listening to mothers and families is also important.

Every day Charles spends time reading, dancing, or playing with his sons in a light-filled room adorned with poster-size photos of Kira posing with family and friends, her smile beaming brighter than the sun's rays. The boys often ask whether Mommy would have liked this song or whether she would have liked playing with their race cars.

Now raising his young sons alone, Charles devotes most of his time to telling Kira's story to health officials, advocacy groups, and even the U.S. Congress.

"More than anything I want people to understand that these women we're losing are more than statistics," he says.

"They're mothers, they're daughters, they're sisters, they're friends," he says. "And they're leaving behind these precious children, and there's no statistic that can quantify what it's like to tell an 18-month-old that Mommy's not coming home. Or to tell a two-year-old, who never will know his mom, how amazing she is." ◻

Veteran journalist **Rachel Jones** focused on health and development issues for a decade in East Africa. **Lynsey Addario** photographed the May 2018 *National Geographic* feature on Muslims in America.

YOUR SHOT

JENNIFER BOGLE

PHOTOS FROM OUR COMMUNITY

WHO

Jennifer Bogle, a lab technician and occasional portrait photographer

WHERE

The emergency room at PeaceHealth St. Joseph Medical Center in Bellingham, Washington

WHAT

A Canon 5D Mark III camera with a 35mm lens

Bogle's daughter, Susannah, then five, caught a stomach virus that landed her in the emergency room after a day of misery. Her face was pale and sunken, and Bogle, a mother of three, was worried. A nurse gave Susannah medicine that helped right away. Bogle, who's seldom without her camera, took this photo as she reflected on "how privileged we were to have this access" to modern medical care. Weeks later, Bogle reports, she was back in the emergency room—this time with her son, whose split lip needed stitches.

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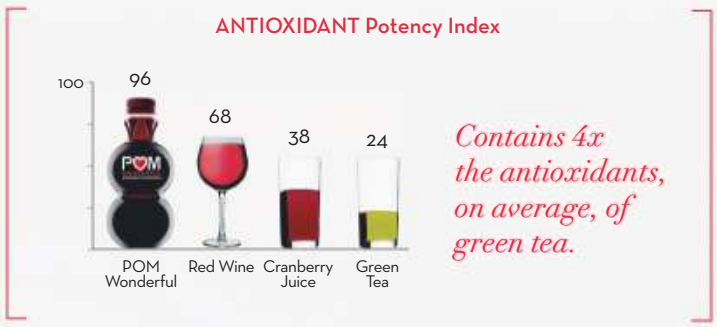
Age to perfection. At any age.

WHY AGE GRACEFULLY, WHEN YOU CAN AGE SUCCESSFULLY? Our bodies can be younger or older than our actual age depending upon diet, lifestyle choices and physical activity. This is called biological age, which could be different than the age on your driver's license, which is called chronological age. A recent study of over 900 adults who were tracked for 12 years, from ages 26-38, showed that people who were aging faster, meaning that their biological age was higher than their chronological age, were not as healthy or physically fit. This group was also more likely to show cognitive decline and was at a greater risk for age-related health conditions.

A growing body of research demonstrates that the keys to aging successfully are a combination of exercising regularly, keeping engaged with life, and maintaining a healthy diet with nutritious foods. These three key elements could contribute to aging gracefully, and successfully, too. POM Wonderful 100% Pomegranate Juice, known for its antioxidants, is part of a healthy diet.

THE ANTIOXIDANT SUPERPOWER IN A BOTTLE. One easy way to get a head start on aging successfully is to add something like POM Wonderful 100% Pomegranate Juice to your daily routine. POM contains pomegranate polyphenols, antioxidants known to combat unstable molecules that can cause damage to your cells. These harmful molecules are called free radicals. To maximize the polyphenol antioxidant levels, every 16oz bottle of POM contains the juice from four whole-pressed pomegranates.



An in vitro study at UCLA found that pomegranate juice has, on average, more antioxidant capacity than red wine, cranberry juice or green tea. It's easy to enjoy all the healthy benefits of pomegranates every day with POM Wonderful 100% Pomegranate Juice. It's great alone or added to your favorite breakfast smoothie. So make POM part of your daily routine. Your body will thank you.

POM Wonderful 100% Pomegranate Juice can be found in the produce section. It is also available on Amazon.

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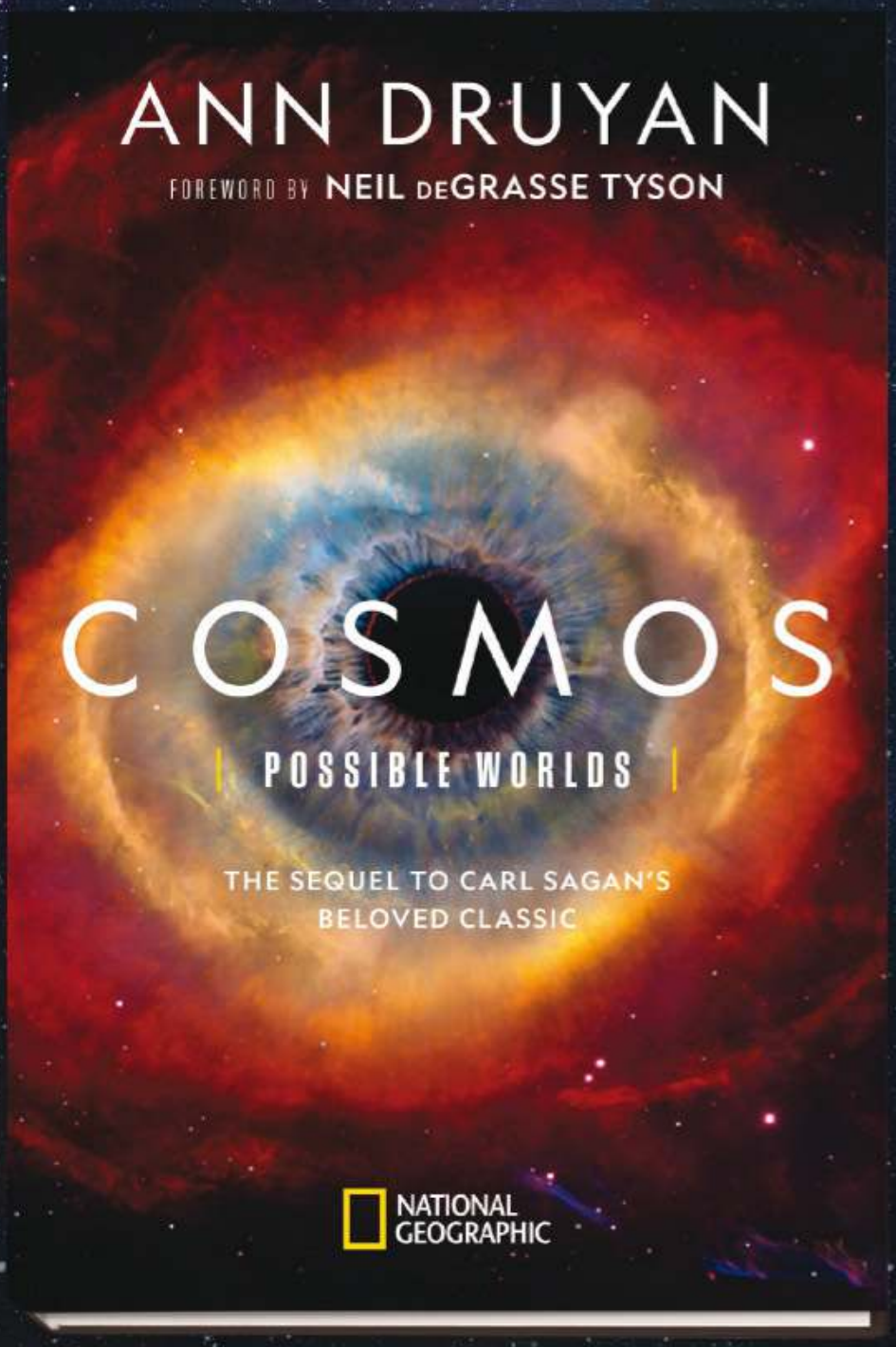
A SAGA MADE OF STARSTUFF



Set sail for the stars in this page-turning odyssey through 14 billion years of cosmic evolution and into the distant future. Lighting your way is Ann Druyan, creative director of NASA's legendary Voyager Interstellar Message Project, co-creator with her late husband, Carl Sagan, of the motion picture ***Contact,*** and Emmy-winning writer of every season of the acclaimed ***Cosmos*** television series. In the pages of this highly anticipated sequel to Sagan's beloved ***Cosmos*** book, you will meet for the first time some of science's most unforgettable searchers and travel alongside them to explore the possible worlds of our cosmos.

Cosmos: Possible Worlds **premieres March 4 on National Geographic**

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